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Study And Analysis Of Biomechanical Parameters Of Human Movement Based On Disability Indicators In Older Adults Through Multifactorial Analysis

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List of publications

This thesis is based on seven original studies translated in 7 articles, detailed below, which collectively contribute to the overall research objectives and provide a comprehensive exploration of the topic.

Study I - Moreira, J. S., Melo, A., Santos, R., & Sousa, A. S. P. (2022). Indicators and Instruments to Assess Components of Disability in Community-Dwelling Older Adults: A Systematic Review. Sensors (Basel), 22(21). https://doi.org/10.3390/s22218270

Study II - Moreira, J., Silva, B., Faria, H., Santos, R., & Sousa, A. S. P. (2023). Systematic Review on the Applicability of Principal Component Analysis for the Study of Movement in the Older Adult Population. Sensors, 23(1), 205. https://doi.org/10.3390/s23010205

Study III – Moreira, J. S., Santos, R., & Sousa, A. S. P. (2024). Methodological considerations for older adult's movement analysis: a scoping review. *Submitted to a scientific journal*

Study IV – Moreira, J. S., Cunha, B., Félix, J., Santos, R., & Sousa, A. S. P. (2025). Kinematic and kinetic gait principal component domains in older adults with and without functional disability: a cross-sectional study. *Submitted to a scientific journal*

Study V – Moreira, J. S., Teles, I., Cunha, B., Félix, J., Guedes, D. C., Alves, L. A. T. Santos, R., & Sousa, A. S. P. (2025). Principal Component Analysis of Stair Negotiation and Floor Transition Kinematics in Older Adults with and without Functional Disability: Cross-sectional Study. *Submitted to a scientific journal*

Study VI – Moreira, J. S., Cunha, B., Félix, J., Santos, R., & Sousa, A. S. P. (2025). Sit-to-stand and stand-to-sit kinematics in older adults with and without functional disability: principal component analysis. *Submitted to a scientific journal*

Study VII – Moreira, J. S., Cunha, B., Félix, J., Santos, R., & Sousa, A. S. P. (2025). Principal component analysis of timed up and go kinematics in older adults: cross-sectional study comparing functional disability status. *Submitted to a scientific journal*

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Abstract

Introduction: Age-related decline and functional disability research present several challenges. **Main objectives:** To identify biomechanical determinants from various functional tasks that characterize the movement of community-dwelling older adults and to distinguish performance between those with and without functional disability. **Methods:** Two systematic reviews and one scoping review were conducted to: identify disability indicators, and respective assessment instruments (Study I); examine the application of principal component analysis in older adults' movement assessment (Study II); and gather guidelines for the kinematic assessment of older adults (Study III). Four cross-sectional studies assessed 60 community-dwelling older adults, with (n=25) and without (n=35) functional disability while performing gait (Study IV), stair negotiation and floor transitions (Study V), sit-to-stand and stand-to-sit transitions (Study VI), and the timed up and go (Study VII) using an optoelectronic system. Tridimensional lower limb joint positions and angular velocities, center of mass displacement and velocity, and other biomechanical variables were analyzed to develop principal component models. **Results:** Functional disability can be characterized by handgrip strength, balance, self-reported health status, basic and instrumental activities of daily living (Study I). Factor analysis has been applied to assess spatiotemporal gait parameters (Study II), and guidelines have been established for this assessment (Study III). Studies IV to VII identified key biomechanical domains defining older adults performance, emphasizing hip and knee control, temporal and variability measures, and trunk kinematics. Biomechanical differences between functional disability groups were observed in gait, stand-to-sit, timed up and go and stair negotiation at pace-related parameters, hip control, trunk kinematics and joint velocities. **Conclusions:** Older adults' biomechanical performance was characterized into domains, revealing structural relationships among variables that also differentiate functional disability.

KEYWORDS: OLDER ADULTS; BIOMECHANICS; KINEMATICS; KINETICS; FUNCTIONAL DISABILITY

Resumo

Introdução: A investigação sobre o declínio relacionado com a idade e a incapacidade funcional enfrenta vários desafios. **Objetivos principais:** Identificar determinantes biomecânicos de várias tarefas funcionais que caracterizam o movimento dos adultos mais velhos residentes na comunidade e distinguir o desempenho entre aqueles com e sem incapacidade funcional. **Métodos:** Foram realizadas duas revisões sistemáticas e uma revisão scoping para: identificar indicadores de incapacidade e respetivos instrumentos de avaliação (Estudo I); examinar a aplicação da análise de componentes principais na avaliação do movimento dos adultos mais velhos (Estudo II); e reunir orientações para a avaliação cinemática destes (Estudo III). Quatro estudos transversais avaliaram 60 adultos mais velhos residentes na comunidade, com e sem incapacidade funcional durante a marcha (Estudo IV), a negociação de escadas e as transições com o chão (Estudo V), as transições de sentado para de pé e de pé para sentado (Estudo VI), e o *timed up and go* (Estudo VII), utilizando um sistema optoelectrónico. As posições tridimensionais das articulações dos membros inferiores e as velocidades angulares, o deslocamento e a velocidade do centro de massa e outras variáveis biomecânicas foram analisadas para desenvolver modelos de componentes principais. **Resultados:** A incapacidade funcional pode ser caracterizada pela força de preensão manual, equilíbrio, estado de saúde auto reportado, atividades básicas e instrumentais da vida diária (Estudo I). A análise fatorial foi aplicada para avaliar os parâmetros espácio-temporais da marcha (Estudo II), e foram estabelecidas diretrizes para esta avaliação (Estudo III). Os estudos IV a VII identificaram os principais domínios biomecânicos que definem o desempenho dos adultos mais velhos, destacando o controlo da anca e joelho, as medidas temporais e de variabilidade e a cinemática do tronco. Foram observadas diferenças biomecânicas entre os grupos de incapacidade funcional na marcha, na posição de pé para sentado, no *timed up and go* e na negociação de escadas em parâmetros relacionados com o ritmo, o controlo da anca e a cinemática do tronco e as velocidades angulares. **Conclusões:** O desempenho biomecânico dos adultos mais velhos foi caracterizado em domínios, revelando relações estruturais entre variáveis que também diferenciam a incapacidade funcional.

PALAVRES-CHAVE: ADULTOS MAIS VELHOS; BIOMECÂNICA; CINEMÁTICA; CINÉTICA; INCAPACIDADE FUNCIONAL

List of abbreviatures

ΔVelocity	Angular velocity range
3D	Three dimensional
ADL	Activities of Daily Living
BMI	Body Mass Index
AIM	Automatic Identification of Markers
AP	Anteroposterior
CCNA	Canadian Consortium on Neurodegeneration in Aging
CoM	Center of Mass
F-S	Floor to stairs
GRF	Groud reaction forces
HGS	Hand Grip Strength
HS	Heel-Strike
IADL	Instrumental Activities of Daily Living
ICF	International Classification of Functioning, Disability and Health
IPAQ	International Physical Activity Questionnaire
KMO	Kaiser-Meyer-Olkin test
M	Mean
ML	Mediolateral
MMSE	Mini Mental State Examination
OLS	One leg standing test
PC	Principal Component
PCA	Principal Component Analysis
PCM	Principal Component Model
PICO	Patient, intervention, comparison, outcome
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
rad	Radians
RoB	Risk of Bias
ROM	Range of Motion
S-F	Stairs to floor
SD	Standard deviation
Sit-to-stand	Sit-TS

SRH	Self reported health status
Stand-to-sit	Stand-TS
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
TO	Toe-Off
TuG	Timed up and Go
WHO	World Health Organization

CHAPTER I - Introduction

The *Introduction* chapter presents the literature review that informed the rationale for this thesis. It is structured into six main themes, addressing the societal and economic impacts of an aging population, the progression of the aging process, the complex interactions between aging, disability, and disease, the role of movement assessment, and the integration of various assessment measures into movement domains.

I.1 Aging on a Global Scale: Societal and Economic Impacts

The term "population aging" refers to the increasement of the number and percentage of the population aged 60 years and older, along with a simultaneous decreased number and percentage of the population aged bellow 15 years (Ismail et al., 2021). Based on this definition, it is undeniable that the world population is aging rapidly, leading to significant social, economic, and health concerns (Beard et al., 2016). The World Health Organization (WHO) anticipates that the number of individuals aged above 60 years will double by 2050, reaching an estimated 2.1 billion (WHO, 2024) which corresponds to approximately 22% of the world's population (WHO, 2024). In addition, global life expectancies are expected to increase, reaching 83 years in more developed regions and 75 years in less-developed regions by 2045–2050. This increase is projected to narrow the gap between life expectancies in more- and less-developed countries, as less-developed regions achieve accelerated gains (Chatterji et al., 2015). Therefore, there will be also a significant increase in the number of the oldest old, meaning, the number of those living to 80 years and over (Mitchell & Walker, 2020).

Research indicates that even if life expectancy is rising globally, people are not always living out their extra years in a healthy condition (Mitchell & Walker, 2020). Health status has a significant impact on the advantages of longer life expectancy, since healthy aging enables older adults participating in fulfilling activities on level alongside younger ones (Beard et al., 2016). Compared to life expectancy this healthy life expectancy increased more slowly, and the difference between both, as the additional years could be characterized by physical or cognitive decline, has significant public health and economic consequences (Beard et al., 2016; Chatterji et al., 2015; Partridge et al., 2018).

To guarantee that social and health systems are prepared to thrive on this demographic transition, all nations must overcome significant challenges (WHO, 2024). It has been estimated that only 12 to 25% of human lifespan is inherited which lives opportunity to make a difference in each person's life (Partridge et al., 2018). Thereby, it is imperative that governments plan ahead and provide sufficient policies and resources to support the growing older population (Ismail et al., 2021). A coordinated and targeted public health response and reforms involving all sectors and stakeholders is required (Beard et al., 2016; Noto, 2023).

I.2 The Aging Process: Biological Pathways and Their Effects

Aging is a physiological multicomponent process, associated with the reduction of reparative and regenerative potential in organisms, and is mediated by several biological and genetic pathways (Costa et al., 2016; Khan et al., 2017; Li et al., 2021). Senescence, the slow and steady deterioration of bodily capacities, is characterized by a diminished physiological reserve in response to stress and a time-dependent disintegration of highly complex molecular processes that eventually lead to disorder (Costa et al., 2016; Khan et al., 2017). This natural process involves cellular alterations that result in decreased oxygen supply to all organs and tissues, impairment of the telomere function, chromosomal instability (Noto, 2023), and protein homeostasis impairment among other processes (Li et al., 2021).

The aging process can be said to begin from the moment a person is born. However, it is from the third decade of age onwards that age-related changes in body composition occur. These changes include the loss of bone, cartilage, and muscle mass, as well as the increase of abdominal fat (Partridge et al., 2018). According to recent research, there are consistent nonlinear patterns in the molecular markers of aging. There are two major periods of significant dysfunction, one occurring at approximately 44 years of age and related to cardiovascular disease, lipid and alcohol metabolism changes, and the other at 60 years of age and related to immune system and carbohydrate metabolism deregulation (Shen et al., 2024). It is also by the 6th decade of life that a decline of muscle size in the lower-limb muscles accelerates reaching up to a 2–3% loss per year, even in healthy individuals (Benavent-Caballer et al., 2016). The combination of molecular changes in the central nervous system, sensory receptors, muscles and peripheral nerves leads to motor deficits and subsequent alterations in movement patterns (Seidler et al., 2010). Although, the decline in physical function is unavoidable, older adults exhibit a wide range of differences, indicating that the effects of aging vary greatly among individuals, and age alone is not a strong predictor of physical function (Manini, 2011; Mitchell & Walker, 2020). This intricate process of declining physical function, influenced by disease conditions and integrated into an individual's social and environmental context, is termed disability (Manini, 2011).

I.3 The Complex Interaction of Aging, Disability, and Disease

The study of the disablement process began in the early 1970s, and the definition of disability has evolved over time (Topinková, 2008). A theoretical model of disablement pathways from pathology, impairment, disability, and handicap was first described. This process is characterized by limitations in activities of daily living (ADL) and a restriction in the performance of socially defined roles within a socio-cultural and physical environment (Nagi, 1965). This model became the basis for the disability classification proposed by the WHO in the early 1980s (Topinková, 2008). Subsequently, other authors expanded the model to include environmental, intra-individual, and risk factors that influence the pathway leading to disability (Verbrugge & Jette, 1994). Taking these models into consideration, the disability classification was updated in 2001 by the WHO and became known as the International Classification of Functioning, Disability, and Health (ICF). The definition of disability was expanded considering that "disability serves as an umbrella term for impairments, activity limitations or participation restrictions" (WHO, 2001).

Nevertheless ICF is not designed to measure disability (WHO, 2001). Disability is typically diagnosed using self-reported questionnaires or performance-based tests (Topinková, 2008), and the application of indicators of morbidity, functional limitations, and disability has been uneven (Christensen et al., 2009). Notwithstanding the widespread acceptance of the notion of disability, methodological problems have made cross-national comparisons of disability prevalence difficult (Topinková, 2008). Various estimates of disability prevalence within surveys, numerous health profiles of described groups, and discrepancies in outcomes for those identified as having a disability are the result of differing definitions of disability and significant variation in its application (Amilon et al., 2021; Stuck et al., 1999). Consequently, the selection of disability measure strongly determines estimates of disability prevalence within surveys, the health profile of specified groups, and inequalities in outcomes (Amilon et al., 2021).

The variation in the onset of disability among individuals of the same chronological age further complicates this process (Kim et al., 2020). The progression from independence to dependence and the aging process are not linear but rather multifaceted courses, intricately tied to biological changes, disease conditions, social and environmental contexts (Manini, 2011). Accordingly, disability can manifest through distinct patterns. In line with different studies, around half of disability cases develop gradually, mainly as a result of chronic illness, comorbidities, and frailty; while the other fifty percent of cases have an abrupt disablement process that results from serious health crises (Topinková, 2008).

For older adults, families, and communities as a whole, the burden of disability, especially those brought on by non-communicable diseases, is enormous (Mitchell & Walker, 2020). According to estimates, 43% of individuals above 60 years have disability (Mitchell & Walker, 2020). This higher rate of impairment frequently results in more illnesses and an increasing dependency from others (Carmona-Torres et al., 2019).

There are also geographical differences in how disability progresses with age, with rates rising significantly between 50 and 70 years of age in Greece, Spain, and Italy, whereas in countries such as the Netherlands, Sweden, Switzerland or United States, the increase is more pronounced after 70 (Chatterji et al., 2015).

Early signs of disability, or "pre-clinical disability", have been identified as a critical stage in the disablement process. According to Manini (2011), this stage functions as an early warning system, much like subclinical disease, where individuals may begin to alter their activity patterns by reducing the frequency of performing everyday tasks or compensating for the difficulty in completing them. Recognizing this stage is crucial for implementing timely interventions that could prevent the full onset of disability (Manini, 2011).

Addressing disability holistically, rather than only target fatal diseases, focusing on prevention, early detection, and the effective management of chronic conditions, offers the most promising opportunity for enhancing the quality of life for aging individuals and minimizing the broader societal and economic impacts of this growing issue (Carmona-Torres et al., 2019; Chatterji et al., 2015; Mitchell & Walker, 2020).

I.4 Aging and Disability: The Role of Movement Assessment

The field of movement analysis, by enabling early detection and subsequent development of prevention programs has a determinant role in identifying kinematic and kinetic parameters that may indicate modifications due to aging and disability.

The variations in movement patterns across different age groups have been extensively documented, primarily through studies comparing gait performance between young and older adults (Abe et al., 2019; Artaud et al., 2015; Boyer et al., 2017; Brach et al., 2007; Perera et al., 2016). In comparing the performance of both age groups, various differentiating factors have been determined. These include reduced hip and ankle joint movements, decreased peak ankle moments, diminished power generation, and lower peak vertical and horizontal ground reaction forces in older adults as compared to young adults (Arnold et al., 2014; Boyer et al., 2017).

Comparative studies investigating older adults with and without functional disability are limited and have primarily focused on the gait analysis. Gait speed and its rate of decline, in particular, has been recognized as a strong indicator of disability in the future (Abe et al., 2019; Artaud et al., 2015; Brach et al., 2007; Perera et al., 2016). Furthermore, variability in stance time has been highlighted as an independent predictor of future mobility disability (Brach et al., 2007).

Numerous functional tests, including gait speed, five times sit-to-stand, one-leg balance stand (OLS), and timed up-and-go (TuG), have been utilized to forecast subsequent ADL and instrumental activities of daily living (IADL) disability (Donoghue et al., 2014; Zhang et al., 2013). However, these studies have primarily relied on clinical outcomes of time performance and have not leveraged the most cutting-edge technological systems to assess movement related adaptations (Ortega-Bastidas et al., 2023).

Furthermore, the definition of incident disability or disability has exhibited considerable variation across studies. Some studies have defined disability based on self-reported new difficulties in walking a half mile or an inability to walk a half mile (Brach et al., 2007), or subjective difficulty in climbing stairs (Jayakody et al., 2023). Others have classified individuals as disabled if they reported challenges with mobility and IADL or with mobility, IADL, and ADL (Artaud et al., 2015; Heiland et al., 2016; Perera et al., 2016). Incident disability was also defined as long-term care insurance certification during follow-up (Abe et al., 2019). The varying criteria used to determine disability makes challenging the comparisons between studies.

The role of movement assessment in aging and disability has recently been explored from new perspectives by authors who acknowledge the multidimensional nature of human movement and the limitations of characterizing it by a single attribute (Hagoort et al., 2023; Hollman et al., 2011; Jayakody et al., 2023; Lord et al., 2013). Consequently, grouping movement characteristics into domains can reveal more effectively the interdependence among individual biomechanical measures (Jayakody et al., 2023; Lord et al., 2013).

I.5 From Isolated Measures to Integrated Domains: Advancing Movement Assessment in Older Adults

As previously noted, individual biomechanical measures are strongly associated with age and/or disability (Abe et al., 2019; Artaud et al., 2015; Brach et al., 2007; Perera et al., 2016). However, many of these measures exhibit significant covariance (Jayakody et al., 2023). Factor analysis methods can uncover the underlying structure within a set of biomechanical measures, reducing redundancies and highlighting the unique properties that define different performance aspects (Hagoort et al., 2023). In particular, Principal Component Analysis (PCA) reduces the dimensionality of biomechanical data by generating a new set of uncorrelated, orthogonal variables, known as principal components (PC)s (Abdi & Williams, 2010; Brandon et al., 2013). PCA is a multivariate, non-parametric statistical technique that identifies latent structures within complex datasets while simultaneously filtering out noise. Its primary objective is to summarize the most critical information across several inter-correlated dependent variables, capturing their variation through a limited set of components that explain the maximum variance (Abdi & Williams, 2010; Wang et al., 2013).

The theoretical foundations of PCA were laid in the early 1900s (Hotelling, 1933; Pearson, 1901), however, its practical application to larger datasets became feasible only with the advent of electronic computing (Jolliffe & Cadima, 2016). In contemporary research, PCA is widely used to identify intricate associations within data captured by advanced motion analysis systems (Phinyomark et al., 2018). It serves several essential purposes: extracting the most relevant information from the data, compressing the dataset by retaining only this key information, simplifying data descriptions, and analyzing the structural relationships among observations and variables (Abdi & Williams, 2010).

The primary goal of PCA, to extract the most important information from the data, has been extensively explored in gait analysis by defining domains that group together the most relevant characteristics. One of the earliest studies in this area was conducted by Verghese and colleagues, 2008, who used factor analysis with the PC method to identify three core components of gait performance in older adults—pace, rhythm, and variability—based on eight individual spatiotemporal gait variables. The authors then analyzed these components to compare gait performance between groups of older adults with and without cognitive impairment (Verghese et al., 2008). Following this work, Hollman and colleagues incorporated additional spatiotemporal gait parameters in their factor analysis, identifying five domains of gait performance: rhythm, phases of the gait cycle, variability, pace, and base of support (Hollman et al., 2011). Lord and colleagues, 2013, further advanced this approach by employing PCA to develop a model validated through a multimethod framework, which included asymmetry and postural control parameters (Lord et al., 2013). More recently, five gait domains were identified—variability, pace, stability, time & frequency, and complexity—with age-related effects observed only in the time & frequency domain (Hagoort et al., 2023). However, inconsistencies persist across different studies. The rationale for selecting specific gait characteristics and determining the number of domains is often unclear, which limits interpretability. Additionally, gait characteristics do not consistently align within the same domains across models, contributing to ambiguity (Lord et al., 2013). Researchers underscore the need for further validation of these models in diverse populations and clinical contexts. Such validation may be essential to accurately identify individuals at elevated risk of adverse outcomes, such as disability, by precisely defining gait function (Lord et al., 2013; Verghese et al., 2008).

Biomechanical studies have also leveraged the second goal of PCA—to compress data by retaining only essential information. Numerous studies have applied PCA to kinematic, kinetic, or electromyography data to reveal underlying coordinative structures within correlated patterns of movement across joints or body segments, thereby effectively reducing the data's dimensionality while capturing essential movement patterns (Wang et al., 2013). One of the earliest studies to apply PCA to the movement of older adults examined the similarity of patients' knee joint force, moment, and angle waveforms throughout the gait cycle. The authors demonstrated that principal component models (PCMs) could quantify deviations from typical gait patterns, allowing for meaningful interpretation based on specific phases of the gait cycle (Deluzio et al., 1997). Since then, multiple studies have employed PCA to reduce data dimensionality in various biomechanical parameters for older adults performing a limited number of tasks. For example, PCA has been used to identify biomechanical features associated with knee osteoarthritis (Deluzio & Astephen, 2007), to reduce time-series marker trajectory data representing whole-body stepping responses (Armstrong et al., 2021), to distinguish gait patterns between young and older adults in stair climbing (Reid et al., 2010), or to extract age and sex differences in normative gait patterns of three-dimensional hip, knee and ankle joint angles and net external moments waveforms (Rowe et al., 2021).

Furthermore, PCA has been utilized as a feature selection method for the automated recognition of gait patterns associated with motor disorders, integrated with machine learning methods (Figueiredo et al., 2018).

I.6 Functional Tasks Biomechanical Domains and A New Frontier in Disability Assessment

The global aging population is experiencing unprecedented growth (Beard et al., 2016), increasing the need for effective policies and the allocation of resources to support an aging population experiencing declines in physical function (Beard et al., 2016; Noto, 2023; WHO, 2024). This decline is influenced by various disease conditions and is intricately embedded within an individual's social and environmental context (Manini, 2011). Despite the widespread acceptance of the concept of disability, differences in assessment methods complicate comparisons across disability studies (Topinková, 2008). A key challenge identified in literature is the lack of consensus regarding the disability assessment and the instruments used for it.

Beyond this, research highlights variations in movement patterns across different age groups (Abe et al., 2019; Boyer et al., 2017; Perera et al., 2016). The distinct movement characteristics of older adults demands tailored analyses to better understand how this population perform various tasks. Furthermore, as previously discussed, human movement is inherently multidimensional and cannot be characterized by a single attribute (Hagoort et al., 2023; Hollman et al., 2011; Jayakody et al., 2023; Lord et al., 2013). Consequently, grouping movement characteristics into domains provides a more effective way to reveal the interdependence among individual biomechanical measures (Jayakody et al., 2023; Lord et al., 2013). This represents the second major challenge identified in the rationale of this thesis.

Additionally, while existing literature acknowledges variations in movement patterns across age groups, most studies predominantly focus on gait performance (Abe et al., 2019; Boyer et al., 2017; Perera et al., 2016). Gait is indeed a critical task for maintaining an independent life, but this emphasis has led to an under exploration of other movement patterns essential for daily activities. The prioritization of the gait task may stem from its centrality for human locomotion as well as its pronounced age-related decline (Kobayashi et al., 2016; Osoba et al., 2019). However, analyzing other functional tasks has also yielded valuable insights into movement patterns among older adults (Buckley et al., 2009; Kuo et al., 2010; Novak & Brouwer, 2011; Reid et al., 2010; Wang et al., 2003), Thus, the third challenge is to extend research beyond gait and investigate a broader range of functional tasks.

Research on movement patterns in older adults primarily compares them to younger age groups (Abe et al., 2019; Boyer et al., 2017; Perera et al., 2016). However, as previously noted, the effects of aging vary significantly among individuals, and age alone is not a strong predictor of physical function (Manini, 2011; Mitchell & Walker, 2020). Consequently, there is a need for studies comparing older adults with and without functional disability. Moreover, studies analyzing these groups often rely on clinical outcomes related to time-based performance (Choo et al., 2021; H. Makizako et al., 2017). While informative and clinical relevant, these have yet to fully leverage state-of-the-art technological systems for a more comprehensive analysis of movement patterns (Ortega-Bastidas et al., 2023). Therefore, literature research highlights a fourth challenge to conduct studies comparing older adults with and without functional disability using biomechanical analysis of these tasks supported by gold-standard technological systems. Comprehensively, research on the determination of movement domains in older adults, and the distinction between those with and without functional disability, allowed the identification of the fourth major challenge.

Accordingly, the first major challenge is the lack of consensus regarding the definitions of disability and the instruments used for its assessment, resulting in significant heterogeneity across studies. Secondly, there is a need to characterize the multidimensional nature of older adults' movement by grouping movement parameters into domains, which better reveals interdependence among individual biomechanical measures.

The third challenge arises from the predominant focus on studying gait task, which has led to the neglect of other essential functional tasks commonly encountered in daily life, such as stair negotiation, transitions from sitting to standing, or initiating walking from a seated position. Finally, the fourth challenge involves the need for comparative studies on older adults with and without functional disability that employ biomechanical analysis of these tasks using gold-standard technological systems.

These challenges also present valuable research opportunities. Specifically, the application of innovative analytical methods, such as PCA, offers a promising approach to grouping and interpreting movement variables that describe movement performance in older adults. PCA can also provide deeper insights into the factors differentiating those who age with and without disability, advancing our understanding of movement patterns in aging populations.

CHAPTER II - Thesis Objectives

The *Thesis Objectives* chapter addresses the main and the specific objectives established for this doctoral thesis based on the literature search performed.

The objectives of this thesis were defined taking in consideration the challenges and opportunities encountered in scientific literature.

Accordingly, the main goal of this thesis is to identify biomechanical determinants from various functional tasks that characterize older adults movement and distinguish the performance of older adults with and without functional disability. To achieve this, several specific objectives have been outlined:

i. To determine the most prevalent and measurable indicators, along with the respective assessment instruments that can identify different components of disability in community-dwelling older adults, based on the ICF framework;
ii. To synthesize existing evidence on the use of PCA in studying the movement of older adults, focusing on kinematics and kinetics and compiling the tasks and biomechanical variables explored in current research;
iii. To gather the guidelines for assessing specific components of older adults' movement, which includes the motor tasks performed by older adults, the association with various outcomes, the motion capture systems used for recording tasks, and the kinematic and kinetic metrics analyzed;
iv. To identify biomechanical determinants for older adults gait, stair negotiation and transition with floor, sit-to-stand (Sit-TS), stand-to-sit (Stand-TS), and TuG performance and those that can distinguish older adults with and without functional disability.

CHAPTER III - Thesis Organization

The chapter *Thesis Organization* outlines the structure of this doctoral thesis and the rationale behind its organization.

This thesis is organized into seven main chapters that outline the rationale, objectives, considerations, and decisions guiding the construction and development of the original studies. Chapter One explores foundational concepts and relevant literature on aging, disability, and movement analysis among older adults, leading to the thesis objectives outlined in Chapter Two. Chapter Three provides an overview of the thesis organization and the logical progression in the development of each study. Chapter Four, *Methodological Considerations*, details the procedures used across study types, which weren't fully addressed in the original papers. Chapter Five presents the complete set of original studies, while Chapter Six discusses the findings, suggests directions for future research, and identifies areas for potential enhancement. The final chapter summarizes the main conclusions and highlights the thesis's contributions to broader scientific research.

The first study addressed the primary objective, identifying the most prevalent and measurable indicators, along with their respective instruments, that can assess various components of disability in community-dwelling older adults, based on the ICF framework. This study was based on a systematic review design and was titled "*Indicators and Instruments to Assess Components of Disability in Community-Dwelling Older Adults: A Systematic Review*" (Study I). Concurrently, another systematic review was conducted to address the second specific objective, resulting in the study "*Systematic Review on the Applicability of Principal Component Analysis for the Study of Movement in the Older Adult Population*", (Study II). The literature search elements ended with the scoping review "*Methodological considerations for older adult's movement analysis: a scoping review*" (Study III) which was conducted to answer the third objective of gathering guidelines and for assessing specific components of older adults' movement.

These systematic and scoping reviews established the foundation and shaped the protocol for subsequent cross-sectional studies. They helped developing a framework to classify older adults with functional disability, to demonstrate how movement performance among older adults has been represented through factor analysis, and what guidelines should be followed when assessing older adults movement.

A cross-sectional study focusing on gait analysis, "*Kinematic and kinetic gait principal component domains in older adults with and without functional disability: a cross-sectional study.*" (Study IV) was deemed necessary, as previous studies has only integrated spatiotemporal parameters to define older adults gait domains, and did not identified the gait domains that distinguish older adults with and without functional disability. The need for further research on additional functional tasks led to development of other three cross-sectional studies. Study V, "*Principal Component Analysis of Stair Negotiation and Floor Transition Kinematics in Older Adults with and without Functional Disability: Cross-sectional Study*" explored stair negotiation and transitions with floor. Study VI entitled "*Sit-to-stand and stand-to-sit kinematics in older adults with and without functional disability: principal component analysis*" investigated Sit-TS and Stand-TS transitions. Finally, the TuG was analyzed in study VII, "*Principal component analysis of timed up and go kinematics in older adults: cross-sectional study comparing functional disability status*".

The work flow and the thesis organization is structured in Figure 1.

This section describes the work conducted throughout the doctoral project that lead to this thesis and to achieve the primary objectives set forth. It is essential, however, to outline the methodological decisions and discuss their underlying rationales before proceeding to a detailed description of the studies produced.

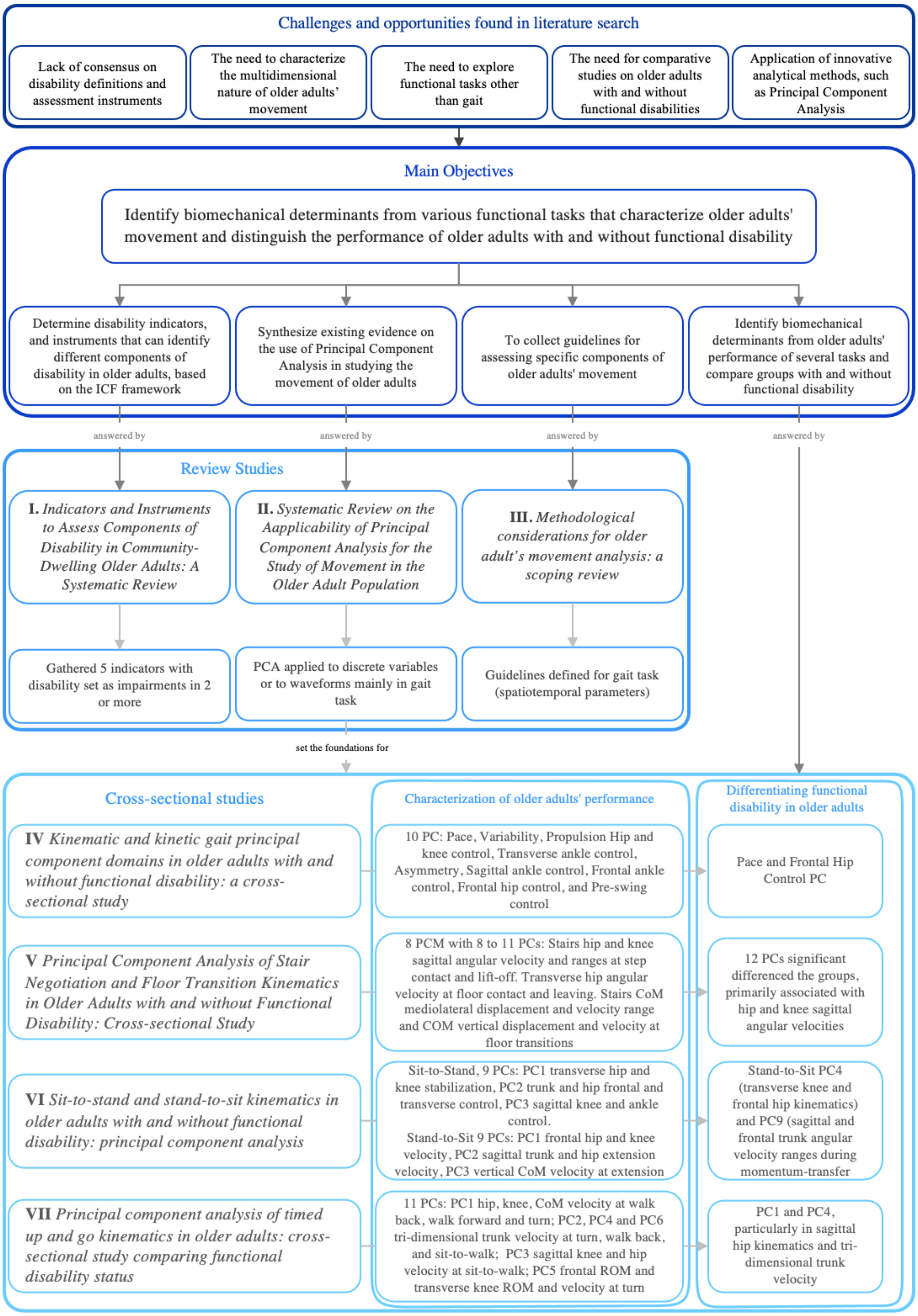

Figure 1: Diagram representing the rationale for the doctoral thesis, along with its objectives, conducted studies, and main findings.

CHAPTER IV - Methodological Considerations

The *Methodological Considerations* chapter presents information that could not be fully addressed in the original studies. It is divided into nine main sections, beginning with the methods of the systematic reviews, the definition of disability used in the cross-sectional studies, and the methodologies of these studies. This chapter also includes ethical considerations, a detailed description of characterization data, disability indicators, and kinematic and kinetic assessments, as well as the rationale for selecting the tasks. Finally, it outlines the data processing details and the procedures adopted for statistical analysis.

The methodology employed in each study comprising this thesis was meticulously researched, analyzed, and deliberated upon, and is clarified in their respective methods section. Although it was not feasible to comprehensively justify all the decisions made within the articles of this thesis, a detailed exposition of the omitted information is presented in the subsequent sub-sections.

IV.1 Systematic Reviews and Scoping review

For both studies I and II, a systematic review design was employed, as this approach facilitates a synthesis of the current knowledge within a particular field. Such syntheses enable the identification of future research priorities and highlight deficiencies in existing primary research that warrant rectification in subsequent studies (Page et al., 2021). Accordingly, a protocol was established for each systematic review in accordance with the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement 2020. The PRISMA 2020 guidelines offer updated reporting standards for systematic reviews, reflecting advancements in methodologies for identifying, selecting, appraising, and synthesizing relevant studies (Page et al., 2021). Both reviews protocols were registered in the International Prospective Register of Ongoing Systematic Reviews, PROSPERO, with registration number CRD42021243416 for study I, and CRD42022329200 for study II. The scoping review followed PRISMA Extension for Scoping Reviews, PRISMA-ScR (Tricco et al., 2018).

IV.2 Defining Disability: Key Indicators for Assessment

The conclusion of the study titled "Indicators and Instruments to Assess Components of Disability in Community-Dwelling Older Adults: A Systematic Review" identified a comprehensive set of indicators and corresponding instruments aimed at elucidating various components of functional disability associated with aging in community-dwelling older adults. This systematic review was grounded in the framework established by the ICF framework. It is essential to emphasize the prevailing lack of consensus regarding the definitions of disability and the instruments employed for its assessment. Considering this, an evidence-based criterion for determining disability was developed for application in cross-sectional studies. An indicator was deemed suitable for inclusion if it appeared in at least three studies, with the stipulation that two of those studies demonstrated good methodological quality according to risk of bias (RoB) assessment. The indicators and instruments that fulfilled these criteria are systematically organized in Table 1.

Table 1: Indicators and respective instruments (described in square brackets) gathered by the systematic review (Study I), the number of studies including the indicator, and number of studies classified with good quality.

Indicator [Instrument]	**Number of studies**	**Number of Good quality studies**
Handgrip strength, HGS [Hand-held dynamometer]	8	6
Cognitive function [Mini Mental State Examination, MMSE]	7	4
Cognitive function [Attention and Visuospatial Ability from Digit from Wechsler Memory Scale-Revised]	4	3
Endurance/ Lower limb strength [Sit-TS time]	4	3
Lower limb strength [Hip/Knee/Ankle maximum concentric and eccentric voluntary contraction]	4	2
Gait speed [Walk test]	6	5
Gait speed [TuG time]	3	1
Balance [OLS time]	3	2
Balance [Berg Balance Scale]	3	2
Overall health status [Self-reported question]	4	3
Functional ability/Physical function ADL [Barthel Index]	3	2
Functional ability/Physical function ADL [Katz Index of ADL]	4	3
Functional ability IADL [Lawton and Brody IADL scale]	4	3
Functional ability IADL [Index of Mobility (Rosow and Breslau)]	3	2

The data presented in Table 1 indicates the presence of multiple instruments suitable for inclusion in the set of disability criteria for cognitive function, lower limb strength, gait speed, balance, ADL, and IADL. In consideration of the study's context, instruments that had already been validated for the Portuguese population at the time of data collection were included. Notably, the selected instruments were the Mini Mental State Examination (MMSE) (Guerreiro et al., 1994), Barthel Index (Araújo et al., 2007), and Lawton and Brody IADL scale (Araújo et al., 2008). Gait speed, as measured by either the walk test or the TuG, was not included, as these tasks would be assessed using an optoelectronic system. The same rationale was considered for the lower limb strength assessed by Sit-TS time. For the balance indicator, the OLS time was chosen due to its significant correlation with the Berg Balance Scale ($r=0.8$, $p<0.001$) and its lower needed time to perform (Nguyen et al., 2012).

Accordingly, handgrip streght (HGS) (measured using a hand-held dynamometer), balance (measured by the time achieved in OLS test), overall self-reported health status (assessed through a self-reported question), ADL (evaluated using the Barthel Index) and IADL (assessed using the Lawton and Brody scale) constituted the functional disability indicators evaluated in the cross-sectional studies included in this doctoral thesis. To meet the criteria for the presence of functional disability, older adults had to exhibit impairments in two or more disability of the listed indicators. The cut-off values are detailed in the section *IV.4 Characterization and Disability indicators assessment*.

This characterization do not include indicators related to environmental factors and body structures, thus in Studies IV to VII, the term "functional disability" was adopted (Yau et al., 2022), as the disability was primary characterized based on body functions, activities and participation domains.

IV.3 Cross-sectional study designs and participants

The cross-sectional studies (IV-VII) were designed in accordance with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (Elm et al., 2008), and the protocol was registered in ClinicalTrials.gov database (register identifier: NCT05611723).

A sample selection questionnaire was distributed to the partner institutions of the Center for Rehabilitation Research at the School of Health of Polytechnic of Porto between June 1, 2022, and March 31, 2023 (Appendix I). An informative flyer accompanied the dissemination email, and in-person presentations of the project were conducted (Appendix II). These included a presentation with information and videos that were created to inform potential participants about the study's objectives and how data collection would be carried out (Appendix III).

Once the older adult agreed to participate voluntarily in the study and met all the inclusion and exclusion criteria, they were contacted, and the assessment was scheduled. Data collection occurred in the movement laboratory of the research center between June 1, 2022, and April 30, 2023.

In the pursuit of the primary objective of the cross-sectional studies, which was to discriminate the movement parameters of older adults and those differentiating between older adults with and without disabilities, a specific set of inclusion criteria was established, commencing with the age category. However, the identification of the age at which a person qualifies as an older adult lacks a clear definition. Most developed nations classify individuals aged 65 or above as "elderly" or older persons, primarily based on the age of eligibility for pension plans. Nonetheless, these classifications lack biological evidence, and certain developed countries are contemplating revising the age threshold due to the increase in healthy life expectancy (Orimo et al., 2006). In light of previous studies indicating noticeable musculoskeletal declines in individuals in their 60s, the present thesis focused on individuals aged 60 years or older (Benavent-Caballer et al., 2016). This decision was corroborated by recent evidence suggesting that an aging dysfunction marker related to the immune system and carbohydrate metabolism deregulation begin to emerge at the age of 60 years (Shen et al., 2024).

The inclusion criteria for this study required participants to be living in the community, as older adults living in institutions tend to experience more pronounced physiological declines due to aging, which can compromise their movement performance (Scheicher et al., 2017).

Furthermore, the final inclusion criterion required that participants demonstrate the capacity to independently perform essential mobility tasks such as walking, sitting, standing, and negotiating stairs. These specific tasks were selected because they closely mirror the movement patterns commonly observed in the daily lives of older adults and are integral to their overall independence. Older adults regularly engage in these activities as part of their daily mobility, with each movement significantly contributing to their overall independence (Tiedemann et al., 2005; Tiedemann et al., 2007). Additionally, the ability to independently perform these tasks was essential as they were evaluated using an optoelectronic system.

Comprehensively, volunteers were excluded from the cross-sectional studies if they were institutionalized. Additionally, potential participants were not included if they had a confirmed diagnosis of malignancy or terminal diseases with an anticipated survival of less than one year, a history of stroke, cerebral hemorrhage, head trauma, or Parkinson's disease, as these conditions have significant and specific implications on movement performance (Defebvre & Krystkowiak, 2016; Krauss, 2015; Radhakrishnan & Goyal, 2018; Wang et al., 2021). Furthermore, individuals were ineligible for participation if they exhibited cognitive impairment, as indicated by a score below 22 on the MMSE (Portuguese version) for 0 to 2 years of literacy, below 24 for 3 to 6 years of literacy, and below 27 for more than 6 years of literacy (Morgado et al., 2009). This criterion was established due to the observed association between cognitive impairment and distinct gait modifications (Peel et al., 2019; Rucco et al., 2017).

Older adults diagnosed with diabetic foot were excluded from the study due to significant differences in kinetics and kinematics when compared to diabetic individuals without neuropathy, as reported in previous research (Hazari et al., 2016).

Potential participants with lower limb fracture in the previous six weeks, unstable cardiovascular disease, liver, or renal function failure were excluded from the study due to concerns that the data collection procedure, which involved the performance of several functional tasks, could have a detrimental effect or exacerbate their health conditions (Muthuswamy, 2013).

Individuals with a body mass index (BMI) exceeding 30 kg/m^2 were excluded from the study, as recent research indicates that obese individuals exhibit unique biomechanical patterns characterized by a variety of kinematic and kinetic deficits (Adouni et al., 2024; Ahsan, 2022).

Another exclusion criterion was the presence of vestibular, auditory, or visual impairments that were not corrected, as these impairments have been documented to have an inverse association with postural stability. Specifically, there is evidence of a link between increasing severity of hearing impairment and poorer performance in Sit-TS, gait and others (Foster et al., 2022).

Finally, in cases where participants exhibit symptoms at the time of assessment that may affect their performance in tasks, such as those related to rheumatic pathologies.

IV.4 Ethical Considerations

The study was conducted in strict accordance with the principles outlined in the Declaration of Helsinki. All participants were thoroughly informed about the study's purpose and methodology, by the referred informative flayers and in-person presentations of the project, and provided written informed consent before participation (Appendix IV). Ethical approval was obtained from the E2S, Polytechnic of Porto Institutional Ethics Committee. The study was submitted for review on April 27, 2022, and received formal authorization on May 25, 2022 (Approval No. CE0064C, Appendix V).

IV.5 Characterization data and Disability indicators assessment

The data collection protocol for the cross-sectional studies commenced with the collection of clinical information. A comprehensive assessment questionnaire was administered, which included items on the presence of health conditions, medication use, healthcare utilization, fear of falling, the occurrence of falls within the previous 12 months (including the falls characterization), and self-reported health status (Appendix VI).

History of fall was assessed through the dichotomous "yes or no" question: "Have you suffered a fall in the previous 12 months?" (Di Giulio et al., 2020; Gerstle et al., 2021). This single-item question was associated with increased positive likelihood odds of falling with a odds ratio 4.2 higher than "American Geriatric/ British Geriatric Screening Questions", with specificity accompanied the "Short Fall Efficacy Scale – International"(Burns et al., 2022). Fear of fall assessment consisted also on a dichotomous "yes or no" question: "Are you afraid of falling?" (Lavedán et al., 2018). This single-item question reliability and criterion validity have been demonstrated in community-dwelling older adults (Toyoda et al., 2022), presenting a good test–retest reliability (0.66) and correlation of 0.723 with the Short Fall Efficacy Scale – International (Oh-Park, Xue, et al., 2011).

Overall self-reported health status (SRH) was evaluated using the question: "*In general, how do you rate your health today? Very bad, Bad, Fair, Good, Very Good*". For analysis, SRH was dichotomized into good ('very good' or 'good') or poor SRH ('fair', 'bad', very bad'). This approach to categorization has been employed in previous studies investigating health trends (Crimmins, 2004), associations with disability (Galenkamp et al., 2012), and the relationship between disability/morbidity and functional ability, where lower functional ability and increased disability were linked to a higher prevalence of fair/poor health (Jamoom et al., 2008; Narayanasamy et al., 2021). After completing the questionnaire, cognitive function was assessed using the MMSE (Appendix VII). ADL were evaluated using the Barthel Index (Appendix VIII)., while IADL were assessed with the Lawton and Brody IADL scale (Appendix IX). Additionally, the self-reported physical activity was assessed by the seven-item short version of International Physical Activity Questionnaire (IPAQ) (Appendix X).

MMSE is a brief screening tool that quantitatively assesses the severity of cognitive impairment and tracks cognitive changes over time (Tombaugh & McIntyre, 1992). In this study, the Portuguese version of the MMSE, adapted and validated for the Portuguese population, was used (Guerreiro et al., 1994). Operational cut-off values, established through analyses of a Portuguese sample, were defined as follows: 22 for individuals with 0–2 years of literacy, 24 for those with 3–6 years of literacy, and 27 for individuals with more than 6 years of literacy (Morgado et al., 2009).

The Barthel Index is an instrument designed to assess an individual's level of independence in performing ten ADL, including eating, personal hygiene, using the toilet, bathing, dressing, sphincter control, walking, transferring from chair to bed, and climbing stairs. This tool was initially described and published by Mahoney and Barthel in 1965 (Mahoney & Barthel, 1965). The scoring system of 0 indicating complete dependency and 20 indicating functional independence was used as this scoring correct for a uneven impression of accuracy (Collin et al., 1988). The Barthel Index has also been validated for use with the Portuguese population (Araújo et al., 2007).

The Lawton and Brody IADL scale, developed in 1969 by Lawton and Brody, evaluates the ability to perform IADL essential for independent living in the community (Lawton & Brody, 1969). The scale has been validated for use with community-dwelling Portuguese older adults (Araújo et al., 2008), and has been widely applied in studies assessing IADLs within this population (Justo-Henriques et al., 2022; Portela et al., 2020). Consistent with previous research, participants are classified as globally dependent if they exhibit impairment in at least one IADL item (Moreira et al., 2016; Sauvel et al., 1994).

Self-reported physical activity was assessed using the IPAQ. This instrument was developed to standardize measurements of health-related physical activity behaviors across diverse countries and sociocultural contexts. The IPAQ has been employed to study physical activity levels in Portuguese older adults (Domingos et al., 2021; Teixeira et al., 2019). Its validity and reliability were confirmed in a 12-country evaluation, which included Portugal (Craig et al., 2003).The short version of the IPAQ consists of seven items addressing moderate and vigorous physical activity (Craig et al., 2003).

Anthropometric measurements were then obtained using a seca® 222 stadiometer (seca—Medical Scales and Measuring Systems®, Birmingham, UK), with a precision of 1 mm for height. Body composition was evaluated using bioelectrical impedance analysis (Tanita Inner Scan BC-601) (Lukaski et al., 1985).

The HGS was measured with a Jamar® Plus+ Digital dynamometer (Performance Health Supply, Cedarburg, WI, USA), with the participants seated, following the standardized protocol recommended by the American Society of Hand Therapists (Fess, 1992; Jansen et al., 2008). Participants were positioned with the shoulder adducted, the elbow flexed at 90 degrees and unsupported, the forearm in a neutral position, and the wrist at 30 degrees of extension. Each participant performed three measurements with the nondominant hand, with a one-minute pause between attempts (Pinheiro et al., 2013). The highest value from the three measurements was recorded. The European Working Group on Sarcopenia in Older People 2, established cut-off values to identify sarcopenia (<27kg for men and <16kg for women). It was used this values since, to the knowledge of the authors there is no normative values of grip strength of Portuguese population along age, with the exception of Mendes et al 2017 (Mendes et al., 2017), that studied older adults above 65 years, and Abdalla et al., 2022 (Abdalla et al., 2022) that studied adults above 50, which applying the conservative measures (≥2.5 SDs below the gender-specific population mean), that cut off values would be 13,9kg for males and 7,35kg for females, and 12,75; 8 respectively.

Balance was assessed by the OLS, measuring the duration a participant could stand on their preferred leg with eyes open. The time, recorded in seconds, was measured until the participant lost balance (e.g., the bent leg touched the ground) or reached the maximum duration of 60 seconds (Chung et al., 2016; Furuna et al., 1998). The ability to successfully complete the 10 seconds is independently associated with all-cause mortality (Araujo et al., 2022).

IV.6 Rationale for Task Selection and Outcome Evaluation in Functional Movement Studies: Advancing Beyond Gait Through Kinematic and Kinetic Innovations

Gait presents as the most frequently studied task, with previous studies having proposed PCMs based on spatiotemporal parameters (Hagoort et al., 2023; Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008). Therefore, gait analysis in older adults required a methodology that not only integrated insights from these existing models but also incorporated an innovative approach that included additional kinematic and kinetic variables. To achieve this, prior models were considered, and a comprehensive literature review was conducted to identify the parameters most strongly associated with aging. A recent systematic review with meta-analysis by Boyer et al., 2017, analyzed the gait mechanics in young and older adults (Boyer et al., 2017). To ensure the relevance of the model, mechanical parameters demonstrating a statistically significant, standardized, moderate-to-large effect of age on gait were selected. Specifically, the chosen kinematic measures included sagittal knee and ankle range of motion (ROM), sagittal ankle angle at toe-off (TO), peak hip extension and peak ankle plantar flexion. The kinetic measures included the second peak of vertical ground reaction force (GRF) (GRF 2nd peak), anteroposterior GRF propulsion peak, sagittal peak ankle power generation and peak ankle dorsiflexion moment. However, this systematic review also highlighted the limitation that most parameters focused primarily on the sagittal plane (Boyer et al., 2017). To address this limitation, lower limb joint ROM and positions at heel-strike (HS) and TO in frontal and transverse planes were also analyzed. Accordingly, the methodology established for gait task analysis incorporated two preliminary PCMs: one replicating spatiotemporal analysis proposed by Lord and colleagues (Lord et al., 2013) and another exploring kinematic parameters in the frontal and transverse planes. The spatiotemporal measures included in the preliminary model replicating the Lord and colleagues (Lord et al., 2013) work encompassed step time and length, variability and asymmetry, stride length, variability and asymmetry, swing and stance time, variability and asymmetry and step velocity, variability and asymmetry. The comprehensive PCA model of gait integrated parameters identified in the systematic review and metanalysis of gait mechanics in young and older adults (Boyer et al., 2017), specifically those demonstrating a statistically significant, standardized, moderate-to-large effect of age on gait. Additionally, significant parameters in the two preliminary models were included.

Beyond gait, additional functional tasks were selected for analysis, including stairs negotiation and transitions with floor, Sit-TS and Stand-TS, TuG. These tasks were chosen because they encompass movement patterns most frequently performed by older adults in daily life (Bohannon, 2015; Cabanas-Sánchez et al., 2019). However, despite their functional significance, they remain underexplored in the literature in terms of biomechanical analysis of older adults' performance. Therefore, a structured approach was adopted in the present doctoral thesis. Initially, a literature review was conducted to determine whether existing PCMs had been developed to classify biomechanical domains of older adults' performance in these tasks. Concurrently, a search was performed for systematic reviews synthesizing the state of knowledge regarding the biomechanical analysis of older adults' task performance. The objective was to integrate insights from previous models while incorporating additional biomechanical features identified in systematic reviews, preferably those including meta-analyses.

Stair negotiation was included in the analysis due to its strong association with disability and functional decline in older adults, given the impairments frequently observed in stair ascent and descent (Tiedemann et al., 2007), as well as the high risk of falls, severe injuries, and mortality associated with stair navigation (Ackermans et al., 2019; Jacobs, 2016). During the literature review, it became evident that a comprehensive assessment of stair negotiation should also account for the transitions between walking and stair ascent (Floor-to-Stairs, F-S) and stairs descent to walking (Stairs-to-Floor, S-F), as these transitions represent the complete daily activity (Bosse et al., 2012; Buckley et al., 2013). Since no prior PCMs or systematic reviews were identified for stair negotiation in older adults, an integrative kinematic analysis approach was adopted. The stair negotiation task was segmented into stair cycles and the F-S and S-F transitions. Data on the position and angular velocity of the hip, knee, and ankle joints were extracted from the ipsilateral limb at the moments of foot contact with the step/floor and foot lift-off from the step/floor. The selected variables included three-dimensional joint positions and angular velocities at these critical phases of stair ascent, stair descent, and the F-S and S-F transitions. Additionally, ROM and the difference between maximum and minimum angular velocities of lower limb joints were calculated for each phase. To ensure a more comprehensive analysis, center of mass (CoM) displacement and velocity range in the three planes (X, Y, Z) were also computed. While previous PCA studies have analyzed stair negotiation in older adults using full waveform analysis for specific parameters (Reid et al., 2010), a discrete variable approach was initially chosen to provide a more detailed analysis of stair negotiation mechanics. This approach aimed to identify critical parameters that explain the greatest variance and best differentiate older adults with and without disability, thereby laying the groundwork for future full-waveform analyses of these parameters.

The Sit-TS and Stand-TS tasks were selected due to their complex, coordinated bilateral lower limb and trunk movements, which pose considerable challenges for older adults due to shifting base-of-support limits (Akram & McIlroy, 2011; Sadeh et al., 2023). The literature review identified a recent systematic review exploring biomechanical and neuromuscular control characteristics of Sit-TS transitions in young and older adults (Sadeh et al., 2023). However, as this systematic review focused exclusively on Sit-TS and lack a meta-analysis, an integrative methodology —similar to that used for stair negotiation—was adopted. Key overall task parameters considered included total duration, CoM acceleration and deceleration, and anteroposterior (AP) and mediolateral (ML) postural sway during Sit-TS and Stand-TS transitions (Sadeh et al., 2023). Additionally, tridimensional lower limb joints and trunk ROM, velocity range, and the CoM displacement and velocity range across different phases of Sit-TS and Stand-TS transitions was considered for the determination of the PCMs. Based on previous literature, Sit-TS was segmented into flexion, momentum-transfer, extension, and stabilization phases, while Stand-to-Sit was segmented into initiation, flexion, momentum-transfer, and extension phases (Alcock et al., 2015; Buckley et al., 2009; Lin & Lee, 2022; Piano et al., 2020). PCA was conducted for each phase to identify the parameters explaining the highest variance, which were subsequently incorporated into global PCMs for Sit-TS and Stand-TS.

The TuG test was included not only because it is a well-established predictor of disability (Choo et al., 2021; Donoghue et al., 2014), but also due to its integration of sit-to-walk, turning, and walking before and after transitions subtasks. The literature underscores the importance of sit-to-walk transitions, as gait initiation often occurs immediately after standing, making this subtask functionally significant (Perera et al., 2022). Furthermore, directional changes are a fundamental component of daily mobility, with studies reporting that up to 50% of daily steps involve turning (Glaister et al., 2007; Riva et al., 2014). Consequently, the rationale applied to other tasks was extended to the TUG. The scarcity of biomechanical studies on TUG and its subtasks was also noted, necessitating an integrative approach. The three-dimensional ROM and angular velocity ranges of lower limb joints and the trunk, as well as CoM displacement and velocity ranges, were assessed during sit-to-walk, walking forward, turn, walking back, and turn-to-sit phases. PCA was performed for each phase, and variables with significant variance were selected to develop a comprehensive PCM of TUG performance in older adults.

IV.7 Kinematic and Kinetic assessment

Following the assessment of characterization data and functional disability features (described in the IV.4 section) the next procedure was the participants preparation for the data collection with the optoelectronic system. The assessment of functional tasks for the collection of kinematic and kinetic data was performed using the Qualisys Track Manager (Qualisys AB®, Sweden). The system incorporated twelve optoelectronic cameras (eight Oquos500, four MiqusM3), one Miqus video camera, and two force plates (FP4060-08/10, Bertec®). This method is considered the gold-standard for movement analysis and allows flexibility of movement, once the subject is unrestricted by wires or other devices, and versatility of movement, allowing to analyze from small motor tasks to human functional activities (Cuesta-Vargas et al., 2010; Neumann, 2010).

Accordingly, participants wore comfortable shoes and clothing suitable for the placement of reflective markers. The placement of markers followed guidelines for reproducible manual and virtual palpations (Jan, 2007), ensuring consistency across participants. The marker setup created and used in all cross-sectional studies, was adapted from collaborative work between the *Istituto Ortopedico Rizzoli* and other researchers (Cappozzo et al., 1995; Leardini et al., 2011; Leardini et al., 2007), with additional modifications to include the head segment (C-motion, 2017) and the Rab Upper Extremity Model (Petuskey et al., 2007). The markers are described in the Table 2 and Figure 2.

Table 2: Anterior and posterior list of markers used in cross-sectional studies.

Marker	Description
Anterior View	
Marker	**Description**
L/RALH	Left/Right anterior head
L/RCAJ	Left/Right acromion
SJN	Deepest point of incisura jugularis
SXS	Xiphoid process, the most caudal point of the sternum
L/RA 1, 2, 3	Left/Right Cluster arm 1, 2, 3
L/RFA 1, 2, 3	Left/Right Cluster forearm
L/RRAD	Left/Right Radio-Styloid process
L/RULN	Left/Right Ulna-Styloid process
L/RIAS	Left/Right anterior superior iliac spine
L/RFTC	Most lateral prominence of the greater trochanter
L/RTH 1, ,2, 3, 4	Left/Right Cluster thigh *1, ,2, 3, 4*
L/RFLE	Most lateral prominence of the lateral femoral epicondyle
L/RFME	Most medial prominence of the medial femoral epicondyle
L/RFAX	Proximal tip of the head of the fibula
L/RTTC	Most anterior border of the tibial tuberosity
L/RSK 1, ,2, 3, 4	Left/Right Cluster shank *1, ,2, 3, 4*
L/RFAL	Lateral prominence of the lateral malleolus
L/RTAM	Most medial prominence of the medial malleolus
L/RFM5	Dorsal margin of the fifth metatarsal head
L/RFM2	Dorsal aspect of the second metatarsal head
L/RFM1	Dorsal margin of the first metatarsal head
L/RDR	Left/Right distal radius
L/RDU	Left/Right distal ulna
Posterior view	
L/RPH	Left/Right posterior head
CV7	Spinous process of the seventh cervical vertebrae
TV2	Second thoracic vertebrae
TV7	Midpoint between the inferior angles of the two scapulae
LV1	First lumbar vertebrae
LV3	Third lumbar vertebrae
LV5	Fifth lumbar vertebrae
L/RIPS	Left/Right posterior superior iliac spine
L/RFCC	Aspect of the achilles tendon insertion on the calcaneous
L/RLELB	Left/Right Lateral Epicondyle of Humerous
L/RMELB	Left/Right Medial Epicondyle of Humerous
L/RMH	Left/Right Medial Head of 5^{th} metacarpal
L/RLH	Left/Right Lateral Head of 5^{th} metacarpal

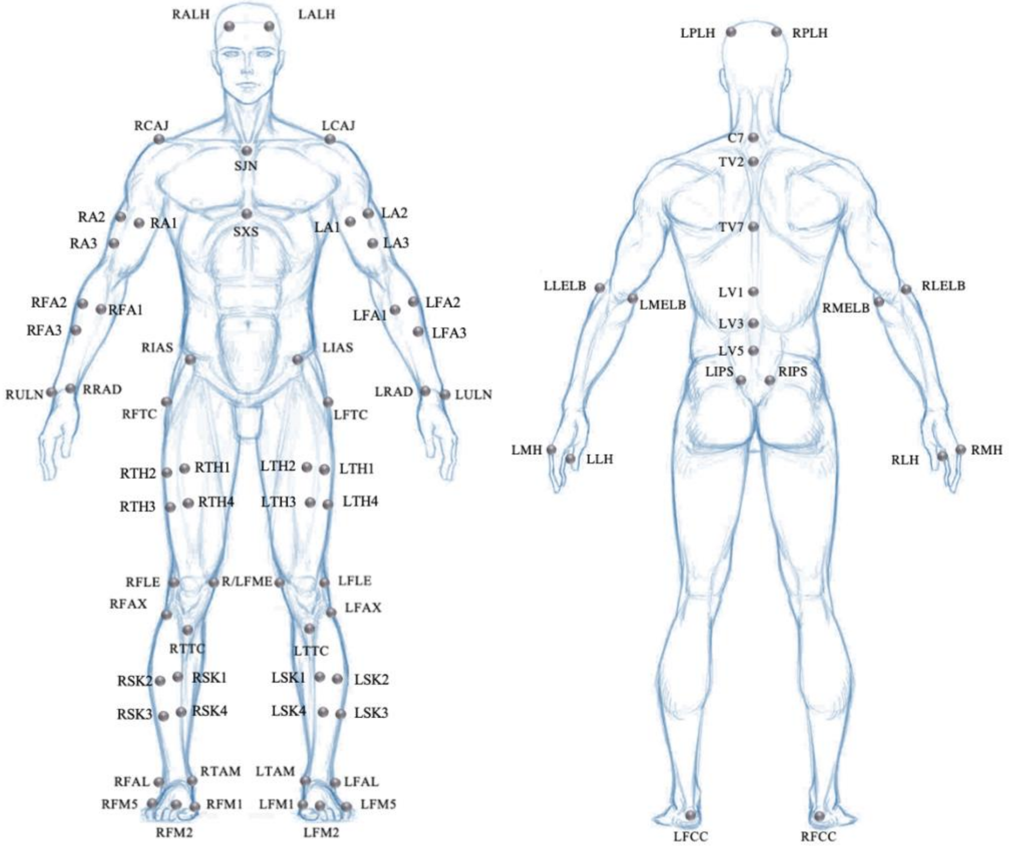

Image adapted from https://paintingvalley.com/full-body-sketch-of-a-man

Figure 2: Anterior and Posterior view of marker setup for cross-sectional studies.

Prior to each data collection session, the camera system was calibrated within a measurement volume sufficiently large to accommodate all task performances while ensuring a successful calibration. This calibration process considered the following factors: (1) the distance (in mm) between the origin of the coordinate system of the motion capture to the optical center of the camera; (2) the number of points used in the calculation of this distance, which should be maximized while maintaining minimal variation between cameras (≤500 mm); and (3) the average residual (in mm) for the selected points, which should be as small and consistent as possible, ideally ranging between 0.5 and 1.5 mm (Qualisys, 2011).

A static trial was conducted with the participant in the anatomical position prior to task performance data collection. This trial served as the foundation for constructing the model of body segments, landmarks, and muscles. Additionally, a movement trial, incorporating motions similar to those performed in the tasks, was conducted for each participant. This trial facilitated the generation of an "Automatic Identification of Markers (AIM)" model in Qualisys Track Manager (Qualisys AB®, Sweden), which identified marker trajectories based on angular and distance relationships. The AIM model was subsequently applied to task performance files to enhance marker tracking accuracy (Qualisys, 2011).

Following these preparatory steps, participants performed the series of functional tasks, including gait, stairs negotiation, TuG and Sit-TS and Stand-TS, ensuring five valid trials for gait and three for the other tasks.

In accordance with task protocol, gait was the first task to be performed. Participants were instructed to walk along a 10-meter straight path on a flat, even surface at a comfortable, self-selected walking speed to assess overground gait (see Figure 3). To ensure a natural gait pattern, participants were allowed sufficient practice walks before data collection. Five successful overground trials, in which each participant correctly stepped on a force plate, were recorded (Kobayashi et al., 2016; Schloemer et al., 2017; Tsuchida et al., 2022). A trial was considered valid if the participant made full-foot contact with the force plate without stepping outside its boundaries (van Kooten et al., 2018). Data collection was conducted in the middle section of the walkway, where force plates were installed in series to capture mid-gait cycles, thereby excluding gait initiation and termination phases (Fuchioka et al., 2015; Svoboda et al., 2017).

A three-step staircase (step height: 16cm, depth: 29cm and width: 69cm) was used for the stair ascent and descent tasks (see Figure 3). On stair ascent, participants began by standing in front of the staircase, positioned before the force plates. They initiated the task with a step on level ground, followed by stepping onto another force plate, and then ascended three steps at a self-selected pace using a step-over-step pattern (Novak & Brouwer, 2011). For stair descent, participants started at the top of the staircase in an upright position with their feet side by side. They were instructed to descend at their self-selected pace, choosing their initiating limb freely (Buckley et al., 2013; Singhal et al., 2014). Upon reaching level ground, participants continued walking for at least two additional steps over the force plates before coming to a stationary standing position, marking the end of the trial (Buckley et al., 2013; Moniz-Pereira et al., 2018). Handrails were available throughout the trials as a safety measure; however, participants were instructed not to use them unless absolutely necessary. Any trials in which the handrails were used were excluded from the analysis. An investigator remained positioned next to the staircase throughout the descent to ensure participant safety. Before the experimental trials, participants performed a practice ascent and descent trial to familiarize themselves with the protocol. Each participant completed and recorded three valid trials for both stair ascent and descent (Kováčiková et al., 2021).

For the TUG task, the researcher first provided a verbal explanation of the test procedure and task execution. Participants were then instructed to rise from a standard chair (seat height: 46 cm), walk at a comfortable pace to a designated line on the floor 3 meters away, turn around, walk back to the chair, and sit down (see Figure 3). The task began with participants seated with their backs against the chair and their arms resting on their laps. They were instructed not to use their arms to help them stand up. To ensure familiarity with the task, participants completed an untimed practice trial before the timed trials. The TUG task was performed and recorded three times (Pisciottano et al., 2014; Podsiadlo & Richardson, 1991).

The Sit-TS and Stand-TS asks were first explained and demonstrated to the participants to ensure confidence in their performance. Participants were instructed to rise from a 46 cm-high chair at self-selected speed with their arms folded across their chest, as can be seen in Figure 3. Before data collection, participants completed three practice trials to determine their preferred foot position in the anteroposterior direction. During the testing, they were instructed to maintain this foot position and avoid repositioning. After achieving an upright standing posture, participants remained still for three seconds before sitting back down (Kuo et al., 2010). Each participant performed three recorded trials (Lin & Lee, 2022).

In all tasks, to maximize safety during the test and reproducibility of the daily living environment, participants were asked to wear comfortable and usual footwear with no heels and wear usual-fitting clothes.

Upon completion of the data collection, a report containing the computable data at that moment was promptly delivered to the participant (Appendix XI).

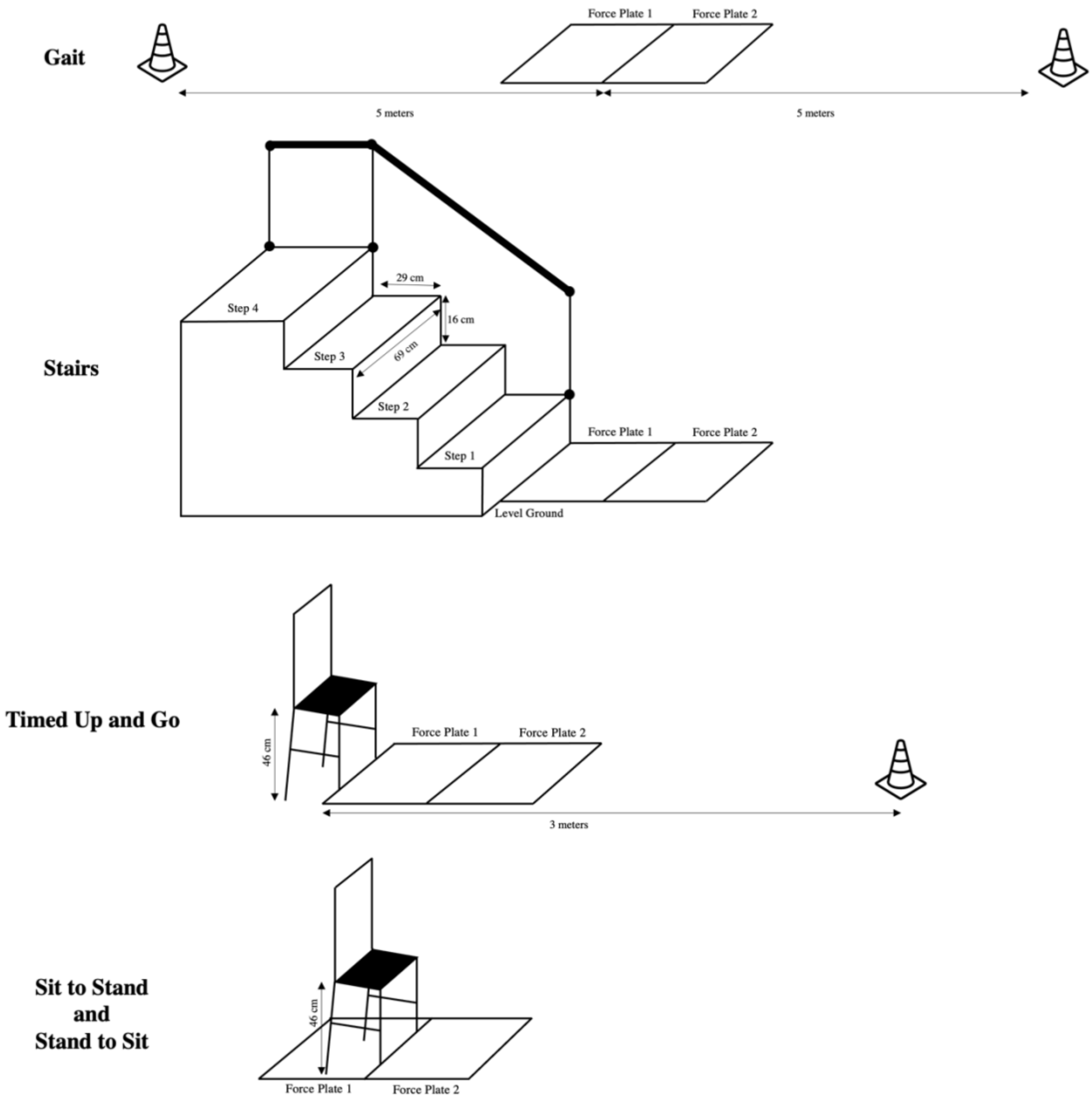

Figure 3: Set up representation for data recording of Gait, Stairs, Timed up and Go, Sit to stand and stand to sit tasks performance.

IV.8 Data processing

For processing data from the cross-sectional studies, Qualisys Track Manager (Qualisys AB®, Sweden) was used to verify and identify markers trajectories, as well as to interpolate path deviations and interruptions using the software's integrated linear, polynomial, and relational calculations. Subsequently, the data were exported to Visual3D Professional™ (C-Motion, Inc, EUA), where the full-body biomechanical model was constructed in accordance with the recommended guidelines from C-Motion (Has-motion, 2024). To eliminate minor random digitization errors and certain soft-tissue artifacts, a Butterworth low-pass filter with a cut-off frequency of 6.0 Hz was applied (Richards, 2018).

The segmentation of tasks into distinct phases was based on previous literature to enhance characterization and capture detailed aspects of older adults' performance during different stages of each task. This segmentation was conducted using Visual3D Professional™ (C-Motion, Inc, EUA), and is described in detail in each cross-sectional study.

In general, the gait task was segmented into gait cycles, or strides, defined as the interval between two consecutive HS of the same foot. Accordingly, outcomes from two left and two right gait cycles were computed for each trial. Stair negotiation was analyzed as a complete daily activity sequence, encompassing walking before stair ascent and after stair descent. This task was divided into specific subtasks, including stair use (stair ascent and descent) and floor transitions: F-S and S-F. Two gait cycles were identified for stair ascent and two for stair descent. The F-S transition was defined as the interval from the moment the foot left the floor to the moment it left the first step, while the S-F transition followed the reverse pattern. Outcomes were also derived from key events, including the instant when the foot left the step or ground and when it made contact with the step or ground. The Sit-TS and Stand-TS tasks were each divided into four phases, following previous research on movement analysis in older adults (Lin & Lee, 2022). Phase segmentation was based on vertical and AP GRF (Buckley et al., 2009; Piano et al., 2020), vertical CoM velocity (Buckley et al., 2009), and sagittal knee angle (Alcock et al., 2015). The Sit-TS was segmented into the following phases: flexion, momentum transfer, extension, and stabilization. Conversely, the Stand-TS task was divided into initiation, flexion, momentum, transfer, and extension (Lin & Lee, 2022). Finally, the TuG was divided into five distinct phases: sit to walk, walk forward, turning, walk back and turn-to-sit (Ansai et al., 2019; Gasparutto et al., 2021).

The selection of outcomes for each task was informed by previous literature. As gait is one of the most extensively studied tasks, prior PCMs for spaciotemporal parameters were considered. Accordingly, gait outcomes included the spatiotemporal measures analyzed using a preliminary model replicating the work proposed by Lord and colleagues (Lord et al., 2013). This model included in the analysis step, swing, and stance time, all measured in seconds; step and stride length (measured in meters); and step velocity (computed in meters per second). Variability and asymmetry were computed for these measures, with the exception of asymmetry in step velocity (Lord et al., 2013). A second primary PCA model focused on lower limb joint ROM and positions at HS and TO in frontal and transverse planes. Thus, the outcomes included in the comprehensive gait PCA model were, in addition to the parameters selected from the previous two models, the angular kinematic and kinetic measures identified in the systematic review and metanalysis of gait mechanics in young and older adults (Boyer et al., 2017), that demonstrated a statistically significant standardized moderate to large effect of age on gait. Specifically, kinematic measures included sagittal knee and ankle ROM, sagittal ankle angle at TO, peak hip extension and peak ankle plantar flexion. Kinetic measures included the second peak of vertical GRF, AP GRF propulsion peak, sagittal peak ankle power generation and peak ankle dorsiflexion moment. For stair negotiation, outcomes included three-dimensional lower limb ROM and angular velocity range for the hip, knee, and ankle joints, extracted from the ipsilateral limb at the moments of step/floor contact and foot-off during stair ascent, descent, and floor transitions (F-S and S-F). The variables selected included ROM and angular velocity range of hip, knee and ankle according to the three axes (X, Y, Z) and at the instant of contact with step and leaving the step at ascent and descent stairs and the contact with floor and leaving the floor at the F-S and S-F transitions. Furthermore, CoM displacement and CoM velocity range in the three planes (X, Y, Z) was also computed for both the stair cycles and the S-F and F-S transitions.

For the Sit-TS, Stand-TS and TuG tasks, outcomes extracted from each phase included hip, knee, and ankle ROM and angular velocity range, as well as CoM displacement and velocity range. Outcomes on specific instants were not retrieved; however, tridimensional trunk joint angles and velocity ranges were included given their relevance on task performance as supported by previous literature (Sadeh et al., 2023).

In all cross-sectional studies, lower limb joint angles (hip, knee, and ankle) and trunk angles were recorded in degrees and calculated using the Cardan sequence. This sequence defines which the x-axis as the medial-lateral (positive for flexion and negative for extension movements), the y-axis as the anterior-posterior (positive for abduction and negative for adduction movements), and the z-axis as the vertical (positive for longitudinal internal and negative for external rotation) in accordance with ISB recommendations for the lower limb (Richards, 2018; Wu et al., 2002).

Joint angular velocities of trunk, hip, knee, and ankle movements were computed in degrees per second, representing the relative angular velocity of one segment relative to another (Richards, 2018). The COM was computed by incorporating all body segments, with segment lengths determined by joint centers, and its position had as resolution coordinate system the laboratory coordinate system (Has-motion, 2024).

ROM was calculated as the difference between the maximum and minimum angle of lower limb and trunk. The difference between the maximum and minimum angular velocities of the lower limb and trunk was defined as angular velocity range.

In the cross-sectional study analyzing gait, inverse dynamics was used to integrate kinematic data with external GRF to derive joint moments and powers at the ankle joint (Dicharry, 2010). Joint moment was normalized to the subject mass. Joint power was computed by combining the joint moments (Nm/kg) and joint angular velocities (rad/s), with positive values for joint power indicating power generation (associated with concentric muscle activity) and negative values indicating power absorption (associated with eccentric muscle activity) (Richards, 2018), with all measures normalized to the subject mass.

A summary of the outcomes included in the cross-sectional studies is provided in Table 3.

Table 3: Summary of tasks, cycles or phases of each task, and the kinematic and kinetic outcomes included in the original cross-sectional studies. º - Degrees; º/s – degrees per second; % GC – percentage of gait cycle; BW – Body weight; m – meters; m/s – meters per second; Nm/Kg – Newton meter per Kilogram; s - seconds; W/Kg – Watt per Kilogram

<table>
<tr><th colspan="5">Study</th></tr>
<tr><th>Study IV</th><th>Study V</th><th colspan="2">Study VI</th><th>Study VII</th></tr>
<tr><td>Kinematic and kinetic gait principal component domains in older adults with and without functional disability: a cross-sectional study</td><td>Principal Component Analysis of Stair Negotiation and Floor Transition Kinematics in Older Adults with and without Functional Disability: Cross-sectional Study</td><td colspan="2">Sit-to-stand and stand-to-sit kinematics in older adults with and without functional disability: principal component analysis</td><td>Principal component analysis of timed up and go kinematics in older adults: cross-sectional study comparing functional disability status</td></tr>
<tr><td colspan="5">Tasks</td></tr>
<tr><td>Gait</td><td>Stairs negotiation</td><td>Sit-TS</td><td>Stand-TS</td><td>TuG</td></tr>
<tr><td colspan="5">Cycles/Phases</td></tr>
<tr><td>Stride</td><td>Stairs ascend
Stairs descend
Floor-to-Stairs
Stairs-to-Floor</td><td>Flexion
Momentum-transfer
Extension
Stabilization</td><td>Initiation
Flexion,
Momentum-transfer
Extension</td><td>Sit-to-walk
Walk forward
Turn
Walk back
Turn-to sit</td></tr>
<tr><td colspan="5">Kinematic variables</td></tr>
<tr><td colspan="5">Sagittal/Frontal/Transverse Hip, Knee, Ankle ROM (º)</td></tr>
<tr><td></td><td colspan="4">Sagittal/Frontal/Transverse Hip, Knee, Ankle angular velocity range (º/s)
AP/ ML/ Vertical CoM displacement (m)
AP/ ML/ Vertical CoM velocity range (m/s)</td></tr>
<tr><td></td><td></td><td colspan="3">Sagittal/Frontal/Transverse Trunk ROM (º)
Sagittal/Frontal/Transverse Trunk velocity range (º/s)</td></tr>
<tr><td>Step, Swing, Stance time (s)
Stride width (m)
Peak Hip Extension (º)
Peak Hip Flexion (º)
Peak Ankle Plantar flexion (º)
Sagittal/Frontal/ Transverse Hip, Knee, Ankle Angle at HS and TO (º)
Step, stance, swing time variability (s)
Step velocity (m/s) and length variability (m)
Step, Swing and Stance Time Asymmetry (% GC)
Step length asymmetry (% GC)</td><td>Sagittal/Frontal/ Transverse Hip, Knee, Ankle at contact/leaving step/floor (º)</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Kinetic variables</td></tr>
<tr><td>Vertical GRF 2nd peak (BW)
Anteroposterior GRF peak (BW)
Ankle Peak Dorsiflexion Moment (Nm/Kg)
Sagittal Peak Ankle Power generation (W/Kg)</td><td></td><td></td><td></td><td></td></tr>
</table>

Additionally, stair negotiation, Sit-TS and Stand-TS, and TuG global characterization variables were compared between older adults with and without functional disability. To characterize the sequences of walk to ascending and descending stairs to walk, the values from cycle time (seconds), speed (meters per second), and peak vertical velocity from the CoM (absolute value in meters per second) were computed. For the Sit-TS and Stand-TS, computed kinematic parameters included task completion time, CoM peak acceleration (Sit-TS) or CoM peak deceleration (Stand-TS), and AP and ML postural sway. The CoM postural sway was measured by the standard deviation of the CoM acceleration (Sadeh et al., 2023). To assess TUG performance, total task time and completion times for each subphase were recorded. These measures were included to provide a comprehensive characterization of older adults' performance, as time-based parameters are primary indicators for Sit-TS, Stand-TS, and TUG. Additionally, these variables facilitated direct comparisons between individuals with and without functional disability.

IV.9 Statistical Analysis

IBM SPSS Statistics for Mac OS, Version 29.0.2.0, was used for data analysis, and a significance threshold was set at 0.05. The demographic and clinical characteristics of the participants were analyzed using means and standard deviations, supplemented by frequency counts to describe categorical variables such as sex, history of falls in the past 12 months, polypharmacy, and SRH status. The normality of the data distribution was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests for groups of older adults without and with disabilities, respectively. Between-group comparisons of demographic and clinical characteristics, as well as task global characterization variables, were conducted using either Mann-Whitney tests or independent sample t-tests, depending on the normality of the distribution. Chi-squared tests were used to evaluate associations between groups for categorical variables, specifically sex, history of falls, and SRH status.

The primary analysis of tasks performance in older adults was conducted using the PCA, given its ability to identify complex associations within data captured by advanced motion analysis systems (Phinyomark et al., 2018). Accordingly, PCA was applied to the kinematic and kinetic outcomes defined for each task. A correlation matrix was constructed to ensure equal contribution of each variable to the analysis, using standardized values where each variable was divided by its standard deviation, resulting in a mean of 0 and a standard deviation of 1.

Potential outliers in the data were manually examined to prevent undue influence on the PCA results. In cases where extreme outliers—defined as values exceeding three times the interquartile range beyond either the first quartile (Q1) or third quartile (Q3)—significantly affected the PCA, data from the corresponding individual were excluded. In all cross-sectional studies, the suitability of the dataset for PCA was assessed by the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett’s Test of Sphericity, which evaluates the appropriateness of the data for reduction. A significant Bartlett's Test result ($p<0.05$) and KMO values exceeding 0.5 were used as criteria for determining the appropriateness of the data for PCA.

PCs explaining the majority of the variance were extracted based on eigenvalues greater than 1. To enhance the interpretability, a Varimax rotation was applied. The rotated component matrix was examined to identify clusters of variables that loaded onto the same components, with a primary focus on variables exhibiting high loadings (loading > 0.7, in accordance with Hair et al. (Hair et al., 1998) for each component. To ensure a more accurate model a stricter loading threshold (>0.8) was applied for variable selection on cross-sectional studies analyzing Sit-TS, Stand-TS and TuG. This decision was made because extreme outliers were excluded from these tasks, reducing the sample size to below 60, thereby justifying a higher loading threshold (Hair et al., 1998). This adjustment aimed to balance interpretability and computational feasibility while retaining only the variables most strongly correlated with the PCs.

Finally, differences between older adults with and without functional disability across each of the kPCs derived from the PCMs for each task were assessed using the non-parametric Mann-Whitney U test, with a significance level set at 0.05.

CHAPTER V – Original Studies

The *Original Studies* chapter present the two systematic reviews and the scoping review that played a crucial role in shaping the methodologies employed in subsequent cross-sectional studies. Following these reviews, the chapter delves into the series of cross-sectional studies that investigate various older adult movement performance, including gait, stair negotiation, sit-to-stand and stand-to-sit transitions, and timed up-and-go tasks. Each of the studies conducted to address the objectives of this thesis is presented in a complete structure. To preserve the integrity of their original formats, the numbering of tables and figures has been reset for each study.

Study I - Indicators and Instruments to Assess Components of Disability in Community-Dwelling Older Adults: A Systematic Review

ABSTRACT

Aging epidemiological demands point to the need of characterizing older adults regarding health and disability. This systematic review aims to summarize indicators (instruments) identifying different components of disability as a result of aging exposition in community-dwelling older adults, considering the International Classification of Functioning, Disability, and Health framework. Taking PRISMA 2020 recommendations as reference, studies with community-dwelling older adults, reporting the development and/or age disability modifications were included. Two reviewers analyzed observational studies searched in the MEDLINE, CINAHL, Web of Science, Scopus, and Embase databases. Of the 137 potentially eligible studies, 49 were included in the review. Several indicators (instruments) demonstrated older adults' disability according to different domains of ICF. Objective measures assessed Body Structures, Body Functions, and Environmental Factors and included handgrip strength (dynamometry, n=8), cognitive function (Mini-Mental State examination, n=7), gait speed (walk test, n=6), and endurance (Chair stand-test, n=4). Self-reported measures assessed Activities and Participation, but not the Body Structures, and included basic and instrumental activities of daily living (ADL) (Katz Index of ADL, n=4 studies, Lawton and Brody Instrumental ADL, n=4 studies). The summary of measures gathered can guide researchers and health professionals in selecting indicators (instruments) to assess and monitor older adults' disabilities resulting to aging exposition, support the development of new wearables, and provide improvements to the existing ones, allowing tailored assessment of different health and disability dimensions.

Keywords: older adults; disability; indicators; aging; systematic review

1. Introduction

Population aging, a consequence of long-term decreased fertility rates combined with increased life expectancy, has led to a contemporary global phenomenon responsible for a multisector societal transformation (Béjot & Yaffe, 2019; Eurostat, 2019). This transformation highlights the need to characterize the older adult population in terms of health, disability, and morbidity measures (Chang et al., 2019; Eurostat, 2019; Statistics, 2016; WHO, 2015) to identify public health problems, plan and evaluate health policies, and guide public health interventions for older adults (Grube et al., 2019; Kilpeläinen et al., 2012).

Comprehensively, aging is a physiological process modulated by several factors, namely, genetic, epigenetic, lifestyle, and environmental (Khan et al., 2017). Through the influence of these modulators, individuals of the same chronological age present significant differences in health, disease, and disability (Khan et al., 2017; Manini, 2011). It should also be considered that age represents a primary risk factor for chronic diseases, including cardiovascular, malignancy, and neurodegenerative conditions, which seem to strongly contribute to older adults' disabilities (Manini, 2011).

The disability concept itself lacks a consensus definition, so different diagnostic measures have been considered (Ebrahim, 1999; Nagi, 1965; Verbrugge & Jette, 1994). Nagi 1965, proposed a theoretical model dividing the disability process into a pathway of four stages or components. The last stage, described as the limitations in activities of daily living (ADL), is characterized by a restriction in the performance of socially defined roles within a social-cultural and physical environment (Nagi, 1965). Later, Verbrugge and Jette, 1994 extended this model, theorizing that extra-individual factors, such as environmental, intra-individual, and risk factors, could influence the pathway that leads to disability (Verbrugge & Jette, 1994). Considering these models, World Health Organization developed, in 2001, the International Classification of Functioning, Disability, and Health (ICF), which states that "disability serves as an umbrella term for impairments, activity limitations or participation restrictions". ICF organizes information into two categories, which are Functioning and Disability (Body Functions and Structures, Activities and Participation) and Contextual Factors (Environmental Factors, Personal Factors), but is not an instrument for measuring disability (WHO, 2001). The disability assessment has been done with self-reported information and/or performance-based measurements (Manini, 2011). Despite the numerous disability measurements, (Freedman et al., 2002; Stuck et al., 1999; Tas et al., 2007) the considerable heterogeneity in the way that disability was defined and categorized has been pointed out as a limitation in previous systematic reviews focused on risk factors (Stuck et al., 1999), prognostic factors (Tas et al., 2007) and the prevalence of disability (Freedman et al., 2002). Moreover, different measures can result in diverse within-survey estimates of disability prevalence, unrelated health profiles of defined groups, and inequalities in the outcomes of people defined as having a disability (Amilon et al., 2021). Two systematic reviews began the process of defining disability measures for the older adult population (Chung et al., 2015; Yang, Ding, et al., 2014). One identified measures of mobility disability in community-dwelling older adults, outlining the need for standardizing instruments for comparison across studies, and for a better understanding of indicators and outcomes of mobility limitation in this population (Chung et al., 2015). Yang et al., 2014 analyzed the contents and formats of general self-reported questionnaires on disability for older adults, gathering 24 questionnaires and comparing their content and formats, stating the difficulty in selecting the best one (Yang, Ding, et al., 2014). Despite the encouraging progress, there is still no definition of the measures that should be used taking into account all domains of ICF and the use of both self-reported and objective measures to assess/monitor the influence of aging on older adults disability.

The measurement of the different components of disability according to ICF framework has an essential role in understanding the aging process and its implications and in planning health programs and services. Moreover, the definition of indicators for different components of disability in older adults could also bring a significant contribution to the development of sensors to assess disability in all ICF domains. Accordingly, the purpose of this study is to systematically review indicators and respective instruments capable of identifying different components of disability as a result of aging exposition, in community-dwelling older adults considering the ICF framework. Specifically, the ICF domains (Body Functions and Structures, Activities and Participation) and Contextual Factors (Environmental Factors) will be used as a reference.

2. Materials and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) (Page et al., 2021) was used as a reference. Systematic reviews should follow a protocol to reduce bias and ensure the findings are reproducible (Sanderson et al., 2007); therefore, the present systematic review protocol was registered in PROSPERO, the International Prospective Register of Systematic Reviews, with the registration number CRD42021243416, and is available at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021243416 (accessed on 15th August 2022).

2.1 Eligibility criteria

The studies had to include community-dwelling older adults (60 years and over) and report the development and/or age modifications of components of disability measures according to the different ICF domains (Body structures, Body Functions, Activities and participation, and Environmental Factors). Observational studies, including cohort and cross-sectional designs, published in English, French, Spanish, or Portuguese, were included. Considering that the aim of the review is to gather the indicators and respective instruments to assess community older adult's disability components, the exclusion criteria for the studies were: 1) studies that considered exclusively older adult's frailty measures, or disability measures specifically designed to evaluate particular pathologies or populations; 2) studies that included individuals with a history of lesions with increasing disability-adjusted life-years, (Avan & Hachinski, 2021; Krishnamurthi et al., 2020) and a high risk of long-term disability (Adamson et al., 2004; Lv et al., 2021; Sousa et al., 2009) in all domains of the ICF (Carvalho-Pinto & Faria, 2016), as well as stroke and dementia, as these conditions are assessed by particular instruments focused on the involved pathological conditions; (3) studies including institutionalized older adults; and (4) studies where the design was meta-analysis, reviews, randomized and non-randomized controlled trials, case reports, pilot studies, technical notes, letters, editorials, or studies published as conference proceedings.

2.2 Information sources and Search strategy

A systematic search was performed in the electronic databases MEDLINE (PubMed), CINAHL, Web of Science, Scopus, and Embase on the 8th of April 2021. Individual search strings were defined for every database, using medical subject headings (MeSH) and free text words in the title and abstract. The reference lists of selected studies, and relevant systematic analysis, were checked by two reviewers to identify additional potential eligible studies. The search strategy, for each database, can be consulted in Supplemental information.

2.3 Selection and data collection process

Following the database search, all potentially eligible studies were retrieved and organized in the EndNote™(Clarivate™London, United Kingdom), version 20, software, where the duplicate publications were deleted. Studies' titles and abstracts were independently assessed by two reviewers, who registered the reasons for exclusion in a table format. Disagreements between the two main reviewers were solved by consensus or by consulting a third independent reviewer in cases where consensus was not achieved. Additionally, two reviewers assessed the full texts of the potentially relevant studies. The flow of the search was displayed according to recommendations made by the PRISMA statement (Page et al., 2021).

The data extraction of the included studies was performed by two reviewers using a pre-defined data extraction table, which retrieved the study identification, study design, sample characteristics, and the indicators with the respective instruments to evaluate them. Missing data from selected studies were requested from the authors via three emails sent over the course of a month and a half.

2.4 Assessment of methodologic quality

The methodological quality risk of bias (RoB) assessment of selected studies is es-sential to interpreting the results, evaluating the strength of evidence found in any systematic review, and reporting information to guide and improve the quality of studies in a particular research area [21,28]. Despite the relevance of the ROB assessment, there is no consensus on how this assessment should be performed on observational studies [29]. In the present review, RoB was assessed by a modified version of Downs and Black [30], adapted to observational studies (test-retest reliability (r=0.88), inter-rater reliability (r=0.75), and internal consistency (KR-20=0.89)), external validity (KR-20: 0.54) and criterion validity (0.89 correlation) (Downs & Black, 1998) by two reviewers (complete description of the items assessed can be consulted in supplemental information). In this modified version (Downs & Black, 1998) ten items of the original checklist that were not relevant to observational studies were removed (items 8, 13 to 15, 17, 19, and 21 to 24). Accordingly, the adapted checklist consisted of 19 items, including 12 items from the original list (Items 1 to 3, 6, 7, 10, 12, 16, 18, 20, and 25); five items that were modified (Items 4, 5, 9, 26, and 27), and two items created by the authors (Rollo et al., 2020). Every quality criterion was given a positive (+) sign, and one point, if the article provided an adequate description of the item, or a negative sign (-), zero point if the publication did not provide an adequate description or did not address and/or perform the quality criteria for the item. Finally, if an unclear description of the item was provided, an “Unable to determine” was assigned, and zero points were attributed. Consequently, the Downs and Black score ranges were given corresponding quality levels: excellent (18-19), good (14-17), fair (10-13), or poor (≤ 9) (Hooper et al., 2008; Rollo et al., 2020).

3. Results

3.1. Literature Search and Study identification, screening and selection

The electronic database search identified a total of 8031 records. From these, 3501 duplicates were removed, resulting in 4530 papers available for the title and abstract screening (Figure 1). The screening of titles and abstracts, performed by two authors with 63% agreement (kappa statistics), identified 136 potentially eligible studies. After discussion, an agreement was reached or consensus was established with the third author. After full-text reading and analysis of the 136 full texts, 49 studies were included in the final analysis (Adachi et al., 2015; Alcock et al., 2015; Amarasena et al., 2018; Andrade et al., 2018; Araújo & Ribeiro, 2011; Arroyo et al., 2007; Barberger-Gateau et al., 1992; Chang & Dong, 2014; Chao et al., 2013; Chen et al., 2012; Choudhary, 2020; Chung et al., 2016; Confortin & Barbosa, 2015; Desrosiers et al., 2009; Dodge et al., 2008; Dong et al., 2014; Ekström et al., 2016; Fastame et al., 2020; Furuna et al., 1998; Ghinescu et al., 2014; Grassi et al., 2020; Hara et al., 2020; Hayashi et al., 2002; Hershman et al., 1995; Ignasiak et al., 2020; Incel et al., 2009; Jansen et al., 2008; Hyuma Makizako et al., 2017; Marques et al., 2014; Moreira et al., 2016; Nakagawa et al., 2017; Nakamura et al., 2017; Neri et al., 2012; Papadakis et al., 1995; Pinheiro et al., 2013; Pisciottano et al., 2014; Poon et al., 1992; Prata & Scheicher, 2012; Romero-Ortuno et al., 2009; Salvà et al., 2005; Sarvestan et al., 2021; Sauvel et al., 1994; Sherman & Reuben, 1998; Smee et al., 2012; Tomita & Burns, 2013; Tomsone et al., 2013; Turner et al., 2016; Uttl et al., 2001; Zunzunegui et al., 2006).

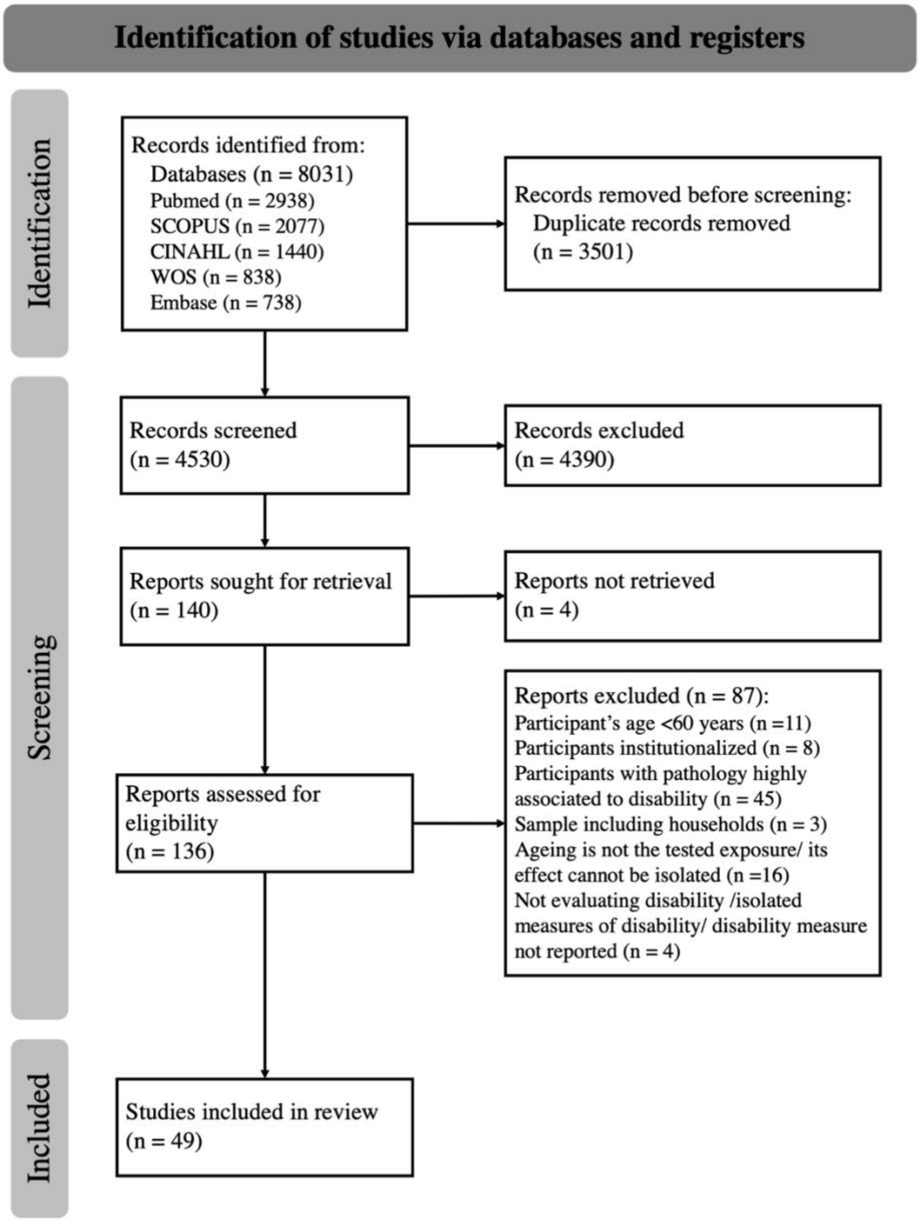

Figure 1: PRISMA 2020 flow diagram for new systematic reviews

Figure 2 reports the number of studies identified and divided into two groups—excluded by title and abstract, (Figure 2A), and included for full-text analysis, (Figure 2B)—by the year of publication, reflecting the evolution of the search for this thematic throughout the years. Over 36% of included studies have a publication year equal to or superior to 2015, and the average publication year of included studies is 2011.

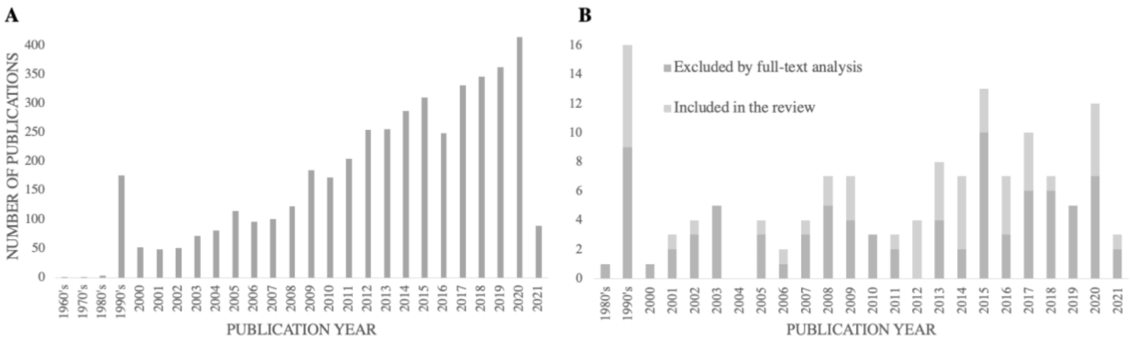

Figure 2: Number of studies retrieved by database search, excluded by title and abstract screening (A), and excluded or included by full-text analysis (B) by publication year.

3.2. Methodological Quality assessment

The methodological quality assessment of the 49 included studies presented in table 1 demonstrates that the Downs and Black total scores ranged from 5 (fair) to 17 (good). 22 of the included studies obtained the classification of good, 24 the classification of fair, and three with the lowest classification class of poor. In the reporting subsection, individual items were completed over 61% of the included sections, excluding the item considering the description of principal covariates, which was only addressed in 39% of the studies. Considering the validity of the studies, the external and the confounding subsection of the internal were addressed by 37% to 78% of studies, while the bias subsection of internal validity was focused on by most of the studies (94% to 100%). The Power description was the subscale that had the fewest articles fulfilled. 37% reported a formal power calculation for determining the association between age and outcome measures, and 4% had a sample size reflective of the power calculation.

Table 1: Scores of the methodological quality assessment, by Modified Downs and Black scale, for the included studies (UD – Unable to determine).

Study Identification	Modified Downs and Black Items and Score																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**S**
1. Adachi et al., 2015	+	+	+	+	+	+	+	+	+	UD	-	+	+	+	+	+	+	-	-	15
2. Alcock et al., 2015	+	+	-	+	-	+	+	+	+	-	-	+	+	+	+	-	+	+	-	13
3. Amarasena et al., 2018	+	+	+	+	-	+	+	+	-	-	+	+	+	+	+	UD	+	-	-	13
4. Andrade et al., 2018	+	+	+	-	-	-	-	UD	-	-	-	+	+	+	+	UD	UD	-	-	7
5. Araújo & Ribeiro, 2011	+	-	-	-	-	+	-	+	-	-	-	-	+	UD	-	-	+	-	-	5
6. Arroyo et al., 2007	+	+	-	+	-	+	+	+	-	+	+	+	+	+	+	UD	+	-	-	13
7. Barberger et al., 1992	+	+	+	+	-	+	+	+	-	+	+	+	+	+	+	UD	+	-	-	14
8. Chang & Dong., 2014	+	+	+	-	-	+	+	-	-	+	+	+	+	+	+	UD	+	+	-	13
9. Chao et al., 2013	+	+	+	+	-	+	-	-	+	+	+	+	+	+	+	UD	-	-	-	12
10. Chen et al., 2012	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+	UD	UD	-	-	13
11. Choudhary, 2020	+	+	-	-	-	+	+	+	+	-	-	+	+	+	+	UD	+	-	-	11
12. Chung et al., 2016	+	+	+	+	+	+	+	+	-	-	-	+	+	+	+	+	-	+	-	14
13. Confortin & Barbosa, 2015	+	+	-	+	-	+	-	+	+	-	-	+	+	+	+	UD	+	-	-	11
14. Desrosiers et al., 2009	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	UD	+	+	+	17
15. Dodge et al., 2008	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	17
16. Dong et al., 2014	+	+	+	+	-	+	+	+	-	-	+	+	+	+	+	UD	+	+	-	14
17. Ekström et al., 2016	+	+	-	+	-	+	+	+	+	-	-	+	+	+	+	UD	+	-	-	12
18. Fastame et al., 2020	+	+	+	-	+	+	+	UD	+	-	-	+	+	+	+	+	UD	-	-	12
19. Furuna et al., 1998	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	+	-	-	-	14
20. Ghinescu et al., 2014	+	+	-	+	-	+	+	+	-	+	+	+	+	+	+	UD	+	-	-	13
21. Grassi et al., 2020	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	UD	+	-	-	14
22. Hara et al., 2020	+	+	+	-	-	-	-	-	+	+	-	+	+	+	+	UD	+	+	+	12
23. Hayashi et al., 2002	+	+	-	+	-	+	+	+	-	-	-	+	+	+	+	UD	+	+	-	12
24. Hershman et al., 1995	+	+	+	+	+	+	+	+	-	UD	UD	+	+	+	-	+	+	-	-	13
25. Ignasiak et al., 2020	+	+	+	+	+	+	+	-	+	-	-	+	+	+	+	+	UD	-	-	13
26. Incel et al., 2009	+	+	+	+	-	+	+	+	-	-	-	+	+	+	+	UD	UD	-	-	11
27. Jansen et al., 2008	+	+	+	+	-	+	+	+	+	-	-	+	+	+	+	UD	+	+	-	14
28. Makizako et al., 2017	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+	-	16
29. Marques et al., 2014	+	+	-	+	+	+	+	-	+	-	-	+	+	+	+	+	-	+	-	13
30. Moreira et al., 2016	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	UD	+	-	-	15
31. Nakagawa et al., 2017	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	UD	+	-	15
32. Nakamura et al., 2017	+	+	+	+	-	+	+	+	+	-	-	+	+	+	+	UD	+	-	-	13
33. Neri et al., 2012	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+	UD	+	-	-	12
34. Papadakis et al., 1995	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+	-	16
35. Pinheiro et al., 2013	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	1
36. Pisciottano et al., 2014	+	+	+	+	-	+	+	+	-	-	-	+	+	+	+	UD	+	+	-	13
37. Poon et al., 1992	+	+	-	-	-	-	-	-	+	-	-	+	+	+	+	UD	-	-	-	7
38. Prata & Scheicher, 2012	+	+	+	+	-	+	+	+	+	-	-	+	+	+	+	UD	+	+	-	14
39. Romero-Ortuno et al., 2009	+	+	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+	-	16
40. Salvà et al., 2005	+	+	+	+	-	-	-	+	-	+	+	+	+	+	+	UD	+	-	-	12
41. Sarvestan et al., 2021	+	+	+	-	+	+	+	+	+	-	-	+	+	+	+	+	+	+	-	15
42. Sauvel et al., 1994	+	+	-	-	-	+	-	+	-	+	+	+	+	+	+	UD	+	-	-	11
43. Sherman and Reuben, 1998	+	+	+	+	-	+	+	+	-	-	-	+	+	UD	+	UD	+	-	-	11
44. Smee et al., 2012	+	+	+	-	-	+	+	+	-	-	-	-	+	+	+	UD	+	+	-	11
45. Tomita & Burns, 2013	+	+	+	+	+	+	-	+	+	+	+	+	+	-	+	+	+	-	-	15
46. Tomsone et al., 2013	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-	-	16
47. Turner et al., 2016	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-	-	16
48. Uttl et al., 2001	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	17
49. Zunzunegui et al., 2006	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+	+	-	-	15
% positive description by item	100	98	76	73	39	92	80	84	61	37	41	96	100	94	96	39	78	37	4	

3.3. Content Analysis

The relevant features for study identification and content analysis were summarized according to their classification in supplementary tables S1- 3. The included studies have a cross-sectional design, except for five studies that presented a longitudinal design (follow-up time ranging between one and ten years). Sample sizes ranged from 24 (Incel et al., 2009) to 10 092 (Hyuma Makizako et al., 2017) older adults, whereas the average of the 49 studies was 1030 participants. Six studies gathered samples including 100% of older adult women (Alcock et al., 2015; Confortin & Barbosa, 2015; Hayashi et al., 2002; Nakamura et al., 2017; Pisciottano et al., 2014; Sarvestan et al., 2021), and one study had the sample integrating only men (Papadakis et al., 1995), the percentage of women in the study samples was between 47% (Smee et al., 2012) and 81.4% (Prata & Scheicher, 2012). Among the studies that identified the age range, an interval between 60 and 105 years has been reported, with a minimal sample age average of 67.4 years (Chao et al., 2013) and a maximal of 80 years (Turner et al., 2016). To report the indicators associated with age, included studies opted mainly for bivariate correlations, Mann-Whitney U test or t-test, Analysis of variance (ANOVA) or Kruskal-Wallis test, and different types of regression analysis as a statistical strategy.

3.3.1. Indicators expressing a statistical association with age

The studies classified as *poor* quality identified statistical associations with age of the indicators: lower extremity's strength/endurance, postural control parameters (Andrade et al., 2018), fluid and crystallized intelligence, primary, secondary and tertiary memory (Poon et al., 1992), vision and audition ability, and ADL assessed by a scale not reported, table S3 (Araújo & Ribeiro, 2011). Nevertheless, these three studies presented significant methodological flaws. In particular, none fulfilled the external validity and power sections and lacked information in the reporting section (table 1). Thereby, considering their results to endorse recommendations could lead to misinterpretation of study data that hereafter would use the measures assessed and described by them.

Table 2 summarizes the indicators, and respective instruments, that identified significant modifications with age assessed by *good* and *fair* quality studies. Indicators assessed by objective measures included the Body Structures, Body Functions, and Environmental Factors. The indicator handgrip strength was used in nine studies (Chung et al., 2016;

Confortin & Barbosa, 2015; Furuna et al., 1998; Hayashi et al., 2002; Incel et al., 2009; Jansen et al., 2008; Hyuma Makizako et al., 2017; Papadakis et al., 1995; Pinheiro et al., 2013), and in eight presented statistical association with age, table S1 and S2 (Chung et al., 2016; Confortin & Barbosa, 2015; Furuna et al., 1998; Hayashi et al., 2002; Jansen et al., 2008; Hyuma Makizako et al., 2017; Papadakis et al., 1995; Pinheiro et al., 2013), from these six have *good* quality, table 1 (Chung et al., 2016; Furuna et al., 1998; Jansen et al., 2008; Hyuma Makizako et al., 2017; Papadakis et al., 1995; Pinheiro et al., 2013). Thereby, it was the most frequent indicator identified as having an association with age and has been objectively assessed with a dynamometer, hydraulic or digital. The cognitive function, when assessed by the Mini-Mental State Examination, was used in eight studies, table S1 and S2 (Barberger-Gateau et al., 1992; Chang & Dong, 2014; Dodge et al., 2008; Nakamura et al., 2017; Neri et al., 2012; Papadakis et al., 1995; Prata & Scheicher, 2012; Uttl et al., 2001) and presented statistical association with age in seven studies (Chang & Dong, 2014; Dodge et al., 2008; Nakamura et al., 2017; Neri et al., 2012; Papadakis et al., 1995; Prata & Scheicher, 2012; Uttl et al., 2001), of which four are of *good* methodology quality, table 1 (Dodge et al., 2008; Papadakis et al., 1995; Prata & Scheicher, 2012; Uttl et al., 2001). Gait speed also identified differences in age even assessed by different instruments (Alcock et al., 2015; Dodge et al., 2008; Furuna et al., 1998; Hyuma Makizako et al., 2017; Pinheiro et al., 2013; Pisciottano et al., 2014; Romero-Ortuno et al., 2009; Sarvestan et al., 2021). The walk test (considering different distances according to the included studies) was the most frequent, being selected by six studies, table S1 and S2 (Alcock et al., 2015; Furuna et al., 1998; Hyuma Makizako et al., 2017; Pinheiro et al., 2013; Romero-Ortuno et al., 2009; Sarvestan et al., 2021), of which five are of *good* quality, table 1 (Furuna et al., 1998; Hyuma Makizako et al., 2017; Pinheiro et al., 2013; Romero-Ortuno et al., 2009; Sarvestan et al., 2021). One of the studies with *good* quality used the GaitRite™ walkway system (Romero-Ortuno et al., 2009). The endurance was also assessed by several tests (Adachi et al., 2015; Alcock et al., 2015; Choudhary, 2020; Confortin & Barbosa, 2015; Dong et al., 2014; Hyuma Makizako et al., 2017; Pinheiro et al., 2013), but the chair stand test was applied in five studies (Alcock et al., 2015; Confortin & Barbosa, 2015; Dong et al., 2014; Hyuma Makizako et al., 2017; Pinheiro et al., 2013), having statistical association with age in four studies, tables S1 and S2 (Confortin & Barbosa, 2015; Dong et al., 2014; Hyuma

Makizako et al., 2017; Pinheiro et al., 2013) of which three are *good* methodology quality, table 1 (Dong et al., 2014; Hyuma Makizako et al., 2017; Pinheiro et al., 2013). Most of the studies measured time to complete the task, but the Alcock et al, 2015, that did not report an association with aging, used an optoelectronic system (Alcock et al., 2015).

*Table 2: A summary of objective and subjective measures with a significant association with age according to the included study (quality classification ≥ fair); studies of fair quality are indicated with a *, and the others correspond to studies of good quality.*

ICF	Indicator	Instrument/Test	Included Studies
Body Structures	Body composition	Digital scale/Dual-emission X-ray densitometer	10* 25* 28 29* 36*
	Teeth/Masticatory function	Dentist, Ultrasonic diagnostic apparatus	22*
Body Functions	Physical Performance	Senior Fitness Test	12 25* 29*
		Physical Performance Test	35 43*
		National Institute on Aging Battery	43*
		Continuous-Scale Physical Functional Performance	44*
	Height, reaction time	Jump test	23*
	Mobility	Get up to sit on a chair	23*
		Sit and reach distance	53*
		Pick-up-a-pen test	35
	Endurance	6 min step test	10*
		Shuttle walking test	1
		Chair stand test	13* 16 28 35
	Gait speed	Walk test	2* 19 28 35 39 41
		Timed up and go	2* 15 36*
		8-foot timed walk	16
	Gait parameters	Dynamic gait index	36*
		Performance Oriented Mobility Assessment	40* 41
	Handgrip strength	Grip test	12 13* 19 23* 27 28 34 35
	Pinch force	Pinch gauges	27
	Manual speed	Maximum finger-tapping rate test	19 23*
	Lower limb Strength	Hip/Knee/Ankle maximum concentric and eccentric voluntary contraction	2* 34 36* 41
	Balance	Four Square Step	11*
		Berg Balance Scale	31 36* 38
	Static balance	Single leg stance test	12 19 23*
		Tandem stand	16 35
	Postural control parameters	Standing test (eyes open)	41
	Cardiorespiratory function: Respiration rate, Breath-holding, Lung capacity, Diastolic blood pressure	TruZone Peak FlowMeter; sphygmomanometer; number of occurrences in a 60-s period	10*
	Cognitive function	Mini-Mental State Exam	8* 15 32* 33* 34 38 48
	Episodic memory	East Boston Memory Test-Immediate and delayed recall	8*

	Prospective, Retrospective memory	The name, letter, and the check task Buschke Recall 1-3; RAVLT A1-6, B1	48			
	Attention and Visuospatial ability	Cancel H, Card sorting	48			
		Digit from Wechsler Memory Scale-Revised	8*	15	34	48
	Executive function	11-item Symbol Digit Modalities Test	8*			
	Psychomotor and executive function	Trail-making A, B from Halstead-Reitan Neuropsychological Test	15	34		
	Semantic Fluency	Verbal fluency, Animal and Picture naming	48			
	Occupational aptitude	General Aptitude Test Battery	23*			
Environmental Factors	Overall morbidity	Total number of medications	15	24*		
	Mobility	Use of mobility devices	17*			
Body Functions	Health status	Short Form Health Survey (SF-36), SF20	2*	20*		
		Elderly Health Assessment Scale	9*			
	Relative health	Self-reported question	7			
	Overall health status	Self-reported question	7	16	20*	21
	Functioning	World Health Organization Disability Assessment Schedule II	21			
	Mental health status	General Health Questionnaire	23*			
	Functional independence	Self-reported question	7	17*		
	Health changes over the last year	Self-reported question	16			
	Morbidity	Number of Chronic conditions	20*			
	Vision/Audition ability	Self-reported question	7	15*		
	Dyspnea/Joint pain	Self-reported question	7			
	Head symptoms	Checklist	17*			
	Mobility	Mobility assessed by a six-level scale	7			
		Self-reported question	45			
	Psychological functioning	Ryff scales of Psychological Wellbeing	17*			
		Psychological Well-Being and Aging Questionnaire	18*			
	Sleep	Questionnaire	47			
Activities and Participation	Functional ability/Physical function ADL	Katz Index of ADL	7	16	30	42*
		ADL Staircase	17*	46		
		Barthel index	10*	31	38	
		Likert-type scale for different tasks	10*			
		Self-reported question	45			
	Functional ability IADL	Lawton and Brody Instrumental Activities of Daily Living Scale	7	16	30	42*
		Tokyo Metropolitan Institute of Gerontology Index of Competence	15	19		
		Self-reported question	45			
	Functional ability AADL/Mobility	Index of Mobility scale (Rosow and Breslau)	6*	7	16	
		Confinement scale	42*			

	Functional ability ADL and IADL	Groningen Activity Restriction Scale	20*	
	Basic physical activities	Index of basic physical activities-Nagi	16	6*
	Social participation	Assessment of Life Habits	14	
	Leisure activities	List of leisure activities	15	
Environmental Factors	Environmental barriers and accessibility problems	Housing Enabler instrument + Functional limitations total number	17*	
	Attachment to home	28-item Meaning of home questionnaire	17*	
	External control beliefs in relation to home	Housing-related Control Beliefs Questionnaire	17*	

Strength of the lower limbs was assessed by a dynamometer or an isokinetic dynamometer in four studies, see Tables S1 and S2 (Alcock et al., 2015; Papadakis et al., 1995; Pisciottano et al., 2014; Sarvestan et al., 2021); reporting the association with age, two of them had a *good* quality methodology, see Table 1 (Papadakis et al., 1995; Sarvestan et al., 2021). Cognitive function, memory, and attention were assessed resorting to the Digit from Wechsler Memory Scale-Revised, which was also used and associated with age in four studies, Tables S1 and S2 (Chang & Dong, 2014; Dodge et al., 2008; Papadakis et al., 1995; Uttl et al., 2001), three having a *good* quality methodology, see Table 1 (Dodge et al., 2008; Papadakis et al., 1995; Uttl et al., 2001).

The remaining indicators, and respective instruments, were assessed and identified as having an association with age in three or fewer included studies.

The indicators that were assessed by subjective measures addressed the Body Functions, Activities and Participation, and Environmental Factors. The most frequently assessed indicator was self-reported health status, evaluated by a single question in eight studies (Amarasena et al., 2018; Araújo & Ribeiro, 2011; Barberger-Gateau et al., 1992; Dong et al., 2014; Ghinescu et al., 2014; Grassi et al., 2020; Uttl et al., 2001; Zunzunegui et al., 2006), although only four reported a significant association with age, see Tables S1 and S2, (Barberger-Gateau et al., 1992; Dong et al., 2014; Ghinescu et al., 2014; Grassi et al., 2020). The Katz Index of Independence in ADL was used in four studies (Barberger-Gateau et al., 1992; Dong et al., 2014; Moreira et al., 2016; Sauvel et al., 1994), all of which found a significant relationship between age and ADL (Tables S1 and S2). The Lawton And Brody Instrumental ADL was applied in the same four studies and by Incel et al., 2009 (Incel et al., 2009) (Table S2), the latter being the only one that has not reported the association of this measure with age. For both instruments reviewed, of the studies that have identified an association with age, three have a *good* quality methodology, see Table 1 (Barberger-Gateau et al., 1992; Dong et al., 2014; Moreira et al., 2016). Functional ability, considering the ADL, was also assessed by the Barthel Index in three of the included studies, see Tables S1 and S2 (Chen et al., 2012; Nakagawa et al., 2017; Prata & Scheicher, 2012), and all of the studies identified a significant association with age, of which two were classified as having a *good* quality methodology, see Table 1 (Nakagawa et al., 2017; Prata & Scheicher, 2012). An identical number of studies applied the Index of Mobility Scale (Rosow and Breslau) to assess functional ability in advanced activities of daily living (AADL), identifying the association with age, see Tables S1 and S2 (Arroyo et al., 2007; Barberger-Gateau et al., 1992; Dong et al., 2014); two were of *good* quality, see Table 1 (Barberger-Gateau et al., 1992; Dong et al., 2014).

Considering the objective measures, the remaining self-reported indicators, and respective instruments, were assessed and identified as having an association with age in one or two of the included studies.

3.3.2. Indicators with an Inconclusive Statistical Association with Age

General health status was assessed by the 12-Item Short-Form Health Survey on the Smee et al., 2012 (Smee et al., 2012) study (Table S2), divided into the physical (physSF-12) and mental (mentSF-12) subscales, with none reporting significant changes with age. The use of the extended scale SF-36 by Incel et al., 2009 (Incel et al., 2009) also did not demonstrate a significant association with age for the total score (Table S2). Alcock et al., 2015 (Alcock et al., 2015) tested this extended version of the scale by dividing it into Mental and Physical Component summaries, with the latter showing a significant relationship with age (Table S2). The only complete version of this scale presenting a statistical association with age was the SF-20 in the Ghinescu et al., 2014 (Ghinescu et al., 2014) study, according to a principal component analysis integrating other indicators into the these factors (Table S2). All the studies that assessed general health status by some version of the Short-Form Health Survey were classified with a *fair* methodological quality, see Tables S1 and S3 (Alcock et al., 2015; Ghinescu et al., 2014; Incel et al., 2009; Smee et al., 2012). More specifically, the self-assessment of health compared to the past, as assessed by Araújo & Ribeiro, 2011 (Araújo & Ribeiro, 2011), did not report a statistical association with age (Table S3).

Body composition was subdivided into several indicators as body mass index (Chen et al., 2012; Chung et al., 2016; Ignasiak et al., 2020; Hyuma Makizako et al., 2017; Marques et al., 2014), fat or lean mass (Papadakis et al., 1995; Pisciottano et al., 2014) or waist circumference (Marques et al., 2014), and assessed by different instruments, such as bioelectrical impedance (Chen et al., 2012; Hyuma Makizako et al., 2017), a weighing scale (Marques et al., 2014), a dual-emission X-ray densitometer (Papadakis et al., 1995; Pisciottano et al., 2014), or integrated into the assessment of the Senior fitness test (Chung et al., 2016; Ignasiak et al., 2020). Globally, body composition was assessed by seven studies (Chen et al., 2012; Chung et al., 2016; Ignasiak et al., 2020; Hyuma Makizako et al., 2017; Marques et al., 2014; Papadakis et al., 1995; Pisciottano et al., 2014), although two did not report any significant association with age, see Tables S1 and S2 (Chung et al., 2016; Papadakis et al., 1995). The studies reporting the association with age were classified mainly as a *fair* methodological quality (Chen et al., 2012; Ignasiak et al., 2020; Marques et al., 2014; Pisciottano et al., 2014), and fewer were of a *good* quality (Hyuma Makizako et al., 2017), Table 1.

The number of medical diagnoses and number of chronic diseases assessed by Araújo & Ribeiro, 2011, see Table S3 (Araújo & Ribeiro, 2011), and Chen et al., 2012, see Table S2 (Chen et al., 2012), respectively, did not present a statistical association with age, but Ghinescu et al., 2014, see Table S2 (Ghinescu et al., 2014), reported an association with age by performing the same statistical procedure applied in the Short-Form Health Survey. Notably, the study of Araújo & Ribeiro, 2011 (Araújo & Ribeiro, 2011), was classified as having a *poor* methodological quality and those of Chen et al., 2012 (Chen et al., 2012) and Ghinescu et al., 2014 (Ghinescu et al., 2014) as *fair* (Table 1). Chen et al., 2012 (Chen et al., 2012), even assessed the frequency of doctor's visits and hospitalization frequency, but did not present a significant association with age (Table S2). Aligned with this indicator, Hershman et al., 1995 (Hershman et al., 1995), assessed the use of non-prescribed medication and the frequency of medication use by category and found that, with the exception of antihistamines and antidepressants, none had a statistical association with age (Table S2).

Ekström et al., 2016 (Ekström et al., 2016) was the only study assessing the indicators related to environmental factors, but two of the ten indicators, in particular, the perception of physical environment support for performance of daily activities in the home, assessed by the Usability in My Home questionnaire, and the housing satisfaction assessed with a single question, did not present an association with age. These authors also assessed the presence of symptoms assessed by a checklist (excluding head symptoms), which did not present a statistical association with age (Ekström et al., 2016) (Table S2).

Neri et al., 2012 (Neri et al., 2012), was the only study that explored language performance by assessing the MMSE sentence (verbal fluency–number of words produced and, grammatical complexity–number of phrases or interrelated ideas), which weren't reported as having a statistical association with age (Table S2).

There were other indicators, and instruments, along with different ranked quality studies, that did not present statistical associations with age. Classified as a *good* quality study, Uttl et al., 2001 (Uttl et al., 2001), did not find an association with age in self-reported eyesight, hearing, and general health, nor in the assessment of sensation by the Color Vision Screening Inventory (Table S1). Fastame et al., 2020 (Fastame et al., 2020), reported associations with age for perceived psychological well-being, but not for the socially desirable response assessed by the inventory in the Marlowe and Crown Social Desirability Scale (Table S2). Poon et al., 1992 (Poon et al., 1992), a study with a *poor* methodological quality, assessed problem-solving ability evaluated by everyday problem resolution, presenting no statistical association with age (Table S3).

There were also three studies in which none of the indicators reported an association with age, particularly, Zunzunegui et al., 2006 (Zunzunegui et al., 2006), classified with a *good* methodological quality (Table S1); Amarasena et al., 2018 (Amarasena et al., 2018), and Incel et al., 2009 (Incel et al., 2009), both classified with a *fair* methodological quality (Table S2). The ADL was the indicator assessed by Zunzunegui et al., 2006 (Zunzunegui et al., 2006), using the Index of basic physical activities (Nagi), a set of questions assessing the difficulty for older adults to perform ADL, and self-reported health, as the instruments. Amarasena et al., 2018 (Amarasena et al., 2018), assessed self-rated oral and general health through a single question, and both did not present a statistical association with age. Two objective measures were assessed by Incel et al., 2009 (Incel et al., 2009), namely dynamometry to evaluate the handgrip strength and finger prehension force to assess the hand-tip pinch. Additionally, Incel et al., 2009 (Incel et al., 2009), used subjective measures (a visual analog scale, the Duruo¨z hand index, the Lawton and Brody IADL scale and, as stated previously, the Short form 36) to assess self-estimated hand function, functional handicap, manual dexterity, IADL performance, and general health. The authors applied *t*-tests and the Mann–Whitney U test and have not reported any significant association with age.

4. Discussion

The present systematic review describes the age-related disability indicators in community-dwelling older adults, which are capable of identifying modifications with age, using the ICF framework as a reference. To our knowledge, this is the first study reporting objective and self-reported indicators for age-related disability components in community-dwelling older adults. To fulfill this purpose, 49 studies assessing the association between aging and the ICF domain indicators, and assessment tools, were included.

Globally, the results of the present study demonstrate an increasing number of studies over the years, which aligns with the increasing socio–economic concerns about the aging population and consequent older adult disability (Béjot & Yaffe, 2019; Eurostat, 2019).

The studies included in the review were exclusively cross-sectional and longitudinal designs, but varied extensively in terms of aims. Study design is of high importance in the gathered instrument's analysis given that the results of cross-sectional studies should be analyzed with caution due to a "cohort effect" (Furuna et al., 1998), and longitudinal studies have a wide range of follow-up periods. The follow-up times of the included studies differed between one and ten years, with every study reporting a significant association of the implemented measures with age, except Zunzunegui et al., 2006 (Zunzunegui et al., 2006), which had a six-year follow-up. Additionally, Moreira et al. 2016 (Moreira et al., 2016), justified the choice of their two-year follow-up, reporting on previous studies that revealed a two-year correlation between functional decline and anthropometric changes with age. Furuna et al., 1998 (Furuna et al., 1998), assessing handgrip strength, reported that a four-year follow-up study could be too short for detecting longitudinal changes in this indicator, but found modifications according to age group in the gait speed during the same period. Therefore, it seems that the time for the follow-up period is not the preeminent factor for identifying modifications associated with age. Nevertheless, it is important to tailor the period to consider the outcome measure being assessed.

Disability, as described in the ICF (WHO, 2001), is a broad term that encompasses several aspects, namely, impairments in body functions and body structures, limitations in activities, and participation restrictions, denoting the negative aspects of the interaction between an individual and his or her environmental and personal factors. Taking this into consideration, and contemplating the objective or self-reported nature of the measures applied, the indicators and respective instruments were divided into the domains of the ICF to which they were more related. It is important to underline that it was a simple and general classification according to the most preponderant domain assessed by the instrument. Currently, there are defined and updated rules for linking health information to the ICF (Cieza et al., 2019), and although some instruments have been subjected to this process (Naughton & Algar, 2019; Stucki & Cieza, 2004; Yang, Luo, et al., 2014), there is still a need for studies that link instruments, and each of their parts or items, with the domains and categories of the ICF.

The objective measures that have identified significant associations with age in the included studies of this review, integrate the ICF domains of body structures, body functions, and environmental factors. In the body functions domain, there is a wide variability of measures, including measures of general function assessed by, for example, the Senior Fitness Test or Physical Performance Test, and more specific indicators such as handgrip strength or gait speed. These measures, along with cognitive function, were the most frequent disability assessment indicators used and identified as having an association with age in community-dwelling older adults in the included studies. In contrast with the handgrip strength assessment, that was performed in all included studies that identified the association with age by dynamometry (Chung et al., 2016; Confortin & Barbosa, 2015; Furuna et al., 1998; Hayashi et al., 2002; Jansen et al., 2008; Hyuma Makizako et al., 2017; Papadakis et al., 1995; Pinheiro et al., 2013), gait speed was assessed by different instruments such as the walk test (Alcock et al., 2015; Furuna et al., 1998; Hyuma Makizako et al., 2017; Pinheiro et al., 2013; Romero-Ortuno et al., 2009; Sarvestan et al., 2021), the Timed up and go (Alcock et al., 2015; Dodge et al., 2008; Pisciottano et al., 2014), and the 8-foot timed walk (Dong et al., 2014). Moreover, gait speed was evaluated only using instrumentalization in one study (Romero-Ortuno et al., 2009). Appropriately, when assessing an ICF component it is important to define the domain and the different level categories, but also to properly describe the instrument used to allow cross-study comparisons. Ultimately, it would be in the greater interest to standardize a selection of reliable instruments, duly linked to the ICF domains and categories, allowing not only the homogenization of research findings, but also the fulfillment of the health care system's needs for indicator-based organization. In fact, it would also be decisive to define for each objective instrument the most accurate electronic device to measure the indicators. To assess the objective measures, different electronic devices were selected such as force plates, dynamometers, and optoelectronic systems, among others. These assessments may also be enhanced by wearable devices since they can effectively track older adults remotely (Chandrasekaran et al., 2021).

Activities and participation can be assessed by self-report, proxy or caregiver statement, or by direct observation (Mlinac & Feng, 2016), but this review found no objective measures to evaluate this domain. This may be due to the longer time it takes to administer training versus self- or informant reports (Mlinac & Feng, 2016). Similarly, it can be argued that there is a difficulty in directly observing the execution of the tasks and actions in the older adult's personal environment. These constraints have resulted in increased efforts to develop self-reported measures in this domain, as evidenced by the number of self-reported instruments found in this review. Yang et al., 2014 (Yang, Ding, et al., 2014), who summarized solely self-reported questionnaires on disability designed for, and/or extensively applied to, the older adults, reported that the main assessed domain was the Activities and Participation domain, while using a different methodology than this review. Additionally, these authors (Yang, Ding, et al., 2014) described that the most regularly used questionnaires were the Barthel Index, followed by the Lawton and Brody Instrumental Activities of Daily Living Scale, and the Katz Index of Activities of Daily Living. The findings of the present review are consistent with those from Yang et al., 2014 (Yang, Ding, et al., 2014), who found that the Katz Index of Activities of Daily Living and the Lawton and Brody Instrumental Activities of Daily Living Scale were identified as having an association with age, in the same four studies (Barberger-Gateau et al., 1992; Dong et al., 2014; Moreira et al., 2016; Sauvel et al., 1994). The Barthel Index was also reported by three studies (Chen et al., 2012; Nakagawa et al., 2017; Prata

& Scheicher, 2012), along with the Index mobility scale (Rosow and Breslau) (Arroyo et al., 2007; Barberger-Gateau et al., 1992; Dong et al., 2014), all underlining the association of these measures with age. It is essential to note that the studies included have identified the association between age and the different categories of activities as the basic, instrumental, and advanced activities of daily living, capturing the progressive degrees of complexity of the daily conduct of an individual (Devi, 2018). Although this review reports the assessment of ADL and IADL through subjective measures, novel methods are being developed to assess the dependence on these activities in older adults using machine learning, and wearable or environmental technologies (Camp et al., 2020; Garcia-Moreno et al., 2022).

The other self-reported indicators and respective instruments were reported to have an association with age in only one or two study results, with the exception of the self-reported question about overall health status reporting an association with age in four of the eight studies reporting it (Barberger-Gateau et al., 1992; Dong et al., 2014; Ghinescu et al., 2014; Grassi et al., 2020), where it was integrated into the body function's domain. The literature recommends self-reported health assessment for screening level community-based health studies (Gallagher et al., 2016) and patient-centered care in clinical settings (Wuorela et al., 2020) and indicates it as a strong predictor of mortality independently of other, more objective health measures (Lorem et al., 2020; Wuorela et al., 2020). However, it should be noted that the studies that included this assessment tool reported different question formulations, with one of them including a thirty-day time frame for the self-assessment of overall health (Grassi et al., 2020).

Considerations regarding the assessment of general health status are also inconclusive, as different versions of the same scale were applied (SF-12, (Smee et al., 2012), SF-36 (Alcock et al., 2015; Incel et al., 2009), and SF-20 (Ghinescu et al., 2014)) and inconsistent results were reported (Alcock et al., 2015; Ghinescu et al., 2014; Incel et al., 2009; Smee et al., 2012). These results are consistent with the divergent literature appraising this specific instrument. There are reports of its effectiveness in evaluating older adults' disabilities (Syddall et al., 2009; Walters et al., 2001), but there are also reports of its limitations on complexity and overestimation of health status results (Parker et al., 2006).

Finally, this review did not find self-reported measures that assessed the body structure domain, which is consistent with the findings of Yang et al., 2014 (Yang, Ding, et al., 2014), because the two reviews did not seek instruments for specific pathologies.

Both objective and subjective measures identified indicators related to the Body functions and Environmental factors domains. The Body structures domain was only assessed by objective measures and the Activities and Participation domain was only assessed by subjective measures. Independently of the applied nature of the instrument, it is fundamental that all domains of the ICF are assessed to accurately evaluate the presence of disability in an older adult. As indicated by the WHO [13], the disability concept encompasses different domains and all of these need to be assessed to profile an individual's functioning. Accordingly, each domain needs to be assessed by different indicators considering the multiplicity of constructs included in each domain. Consider the body functions domain, which was defined by thirty-six indicators and assessed by even more instruments. A need for filtering these measures has been identified. Although this review identifies a set of indicators that report modification along with the aging process, it is necessary to define which indicators are more suited to assess the different constructs within each domain.

As the ICF conceptualizes disability as a health experience that occurs in a context, every domain should be assessed to look at medical, individual, social, and environmental influences on functioning and disability (Kostanjsek, 2011). Different categories of older adults' functioning have been studied (Spoorenberg et al., 2015; Tomandl et al., 2021), and some relevant ones have been proposed (Book et al., 2020; Vasconcelos et al., 2022). However, each domain has been assessed independently and, therefore, the integration of the ICF domains into single measures is needed (Rejeski et al., 2008). The usage of technologies in the different instruments to evaluate disability, such as wearables (Chandrasekaran et al., 2021) or optoelectronic systems (Alcock et al., 2015), for assessing ICF domains could improve the objectivity of the measures, be cost-effective and decrease assessment time. Even the implementation of the ICF coding itself can be improved by using health technology (Zhang et al., 2020), as its information technology infrastructure for documenting, coding, and reporting has been identified as poor (Leonardi et al., 2022). There were several indicators, and instruments, that presented an association with age only in one of the included studies. Consequently, raising considerations regarding these measures could be premature, and further studies are necessary to assess their association with age.

Limitations

The results of this review must be interpreted, bearing in mind that gray literature was not included in the search. Nevertheless, to overcome that, and to ensure the retrieval of higher-quality studies, a set of complementary databases were used. Additionally, the summary of the indicators, and respective instruments, comprised the ones identified by the included studies with *good* and *fair* methodological qualities. Therefore, when consulting the results of the present review, researchers and health care professionals will be able to easily distinguish the indicators identified by the *fair* and *good*-quality studies and interpret their results accordingly.

The indicators and respective instruments summarized in this review identified modifications along with age. However, the report or calculation of the related validity, feasibility, and repeatability of each of the instruments should be addressed in future studies, taking as a reference the, in-development, PRISMA–COSMIN guidelines (Elsman et al., 2022). This evaluation will allow for the selection of instruments with superior psychometric properties.

In future research, it will be necessary to gather all the instruments that have been formally linked to the ICF to understand which reliable, and frequently applied instruments need to be further linked to allow the comparability of information. According to Cieza et al., 2019 (Cieza et al., 2019), allowing the comparability of data is essential for consistency between decision-makers at all levels of health care organizations.

5. Conclusions

This review identified 49 studies, including the outcome assessments used to measure disability in community-dwelling older adults. Most of the included studies reported indicators, and respective assessment tools, that identified significant modifications with age. The conjunct of the studies has identified that self-reported and objective instruments can assess the four domains of the ICF. The indicators assessed by objective measures included Body Structures, Body Functions, and Environmental Factors of the ICF. The most frequent indicators (identified in four or more of the included studies), and respective instruments, that presented a significant association with age, were handgrip strength (dynamometry, *n* = 8), cognitive function (Mini-Mental State examination, *n* = 7), gait speed (walk test, *n* = 6), endurance (Chair stand-test, *n* = 4), strength of the lower limbs (dynamometry *n* = 4) and cognitive function, and memory and attention (Digit from Wechsler Memory Scale-Revised, *n* = 4). The assessment of activities of daily living (ADL) (Katz Index of ADL, *n* = 4 studies) and the instrumental ADL (Lawton and Brody Instrumental ADL, *n* = 4 studies) was carried out using self-reported measures that included activities and participation, but not body structures. However, there were no objective measures assessing the Activity and Participation domain nor the self-reported measures assessing the Body Structures domain. The measures summary gathered by this review may be significant for researchers and health care professionals to select a set indicators, and respective instruments, that effectively identify changes in disability with age, comprehending the four domains of the ICF. Additionally, several indicators can be assessed by electronic devices, or wearable technologies, so establishing the indicators best suited to assess older adults' health and disability can support the development of new wearables and provide improvements to the existing ones.

Supplementary Materials (Appendix XII): downloaded at: https:// www.mdpi.com/article/10.3390/s22218270/s1, Supplemental Information: Complete search strategy and reference of excluded studies by full-text analysis; Table S1: Characterization and summary of studies included in the review with classification of "Good" in Downs and Black scale, listed by decreasing order of quality score (for those with the same score an alphabetic order was used); Table S2: Characterization and summary of studies included in the review with classification of "Fair" in Downs and Black scale, listed by decreasing order of quality score (for those with the same score an alphabetic order was used); Table S3: Characterization and summary of studies included in the review with classification of "Poor" in Downs and Black scale, listed by decreasing order of quality score (for those with the same score an alphabetic order was used).

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Study II - Systematic Review on the Applicability of Principal Component Analysis for the Study of Movement in the Older Adult Population

ABSTRACT

Principal component analysis (PCA) is a dimensionality reduction method that has identified significant differences in older adults' motion analysis previously not detected by the discrete exploration of biomechanical variables. This systematic review aims to synthesize the current evidence regarding PCA use in the study of movement in older adults (kinematics and kinetics), summarizing the tasks and biomechanical variables studied. From the search results, 1685 studies were retrieved, and 19 studies were included for review. Most of the included studies evaluated gait or quiet standing. The main variables considered included spatiotemporal parameters, range of motion, and ground reaction forces. A limited number of studies analyzed other tasks. Further research should focus on the PCA application in tasks other than gait to understand older adults' movement characteristics that have not been identified by discrete analysis.

Keywords: principal component analysis; biomechanics; kinematics; kinetics; older adults

1. Introduction

The older adult population, those with age above 60 years, will increase in the coming decades in Europe (Eurostat, 2020). Accounting for almost half of the total health costs (Kalseth & Halvorsen, 2020), the aging population will increase the burden on healthcare services (EU, 2021) expressed through an estimated increase from 3% to 4% in gross domestic product from 2004 to 2050 (Tinker, 2002).

Biological aging can be defined as the progressive loss of function and represents a constant decrease in multisystemic capacity (Adams & White, 2004; Ganea et al., 2011; Salzman, 2010) that can be expressed in changes in movement patterns in various tasks (Seidler et al., 2010). Different biomechanical analyses have been associated with fall risk in older people, such as the displacement of the center of pressure in the standing position (Howcrof et al., 2017), decreased speed, stride length, and single limb support time in gait (Herssens et al., 2018). Other movement modifications were identified due to the aging process, such as decreased lumbar range of motion (Kuo et al., 2010) during sit-to-stand, an indicator of functional independence in daily life (Dall & Kerr, 2010). However, because these findings have been obtained from discrete approaches, such as descriptive statistics and statistical inference based on only some parameters of the waveform (Herssens et al., 2018; Kuo et al., 2010), there is a consistent risk of information loss (Phinyomark et al., 2018). Additionally, other clinical measures assessed by classical psychometric procedures may have led to dubious conclusions (Pellicciari et al., 2019), while others discarded several parts of the information and required a greater number of trials from participants before drawing conclusions (Benson et al., 2019). Advanced multivariate analysis and machine learning methods have been applied to fully translate the complexity of the interactions between the variables (Phinyomark et al., 2018). Principal component analysis (PCA) is a multivariate statistical technique that reduces the volume of data to a smaller number, considering all the information captured (Brandon et al., 2013; Kirkwood et al., 2011). PCA uses an orthogonal transformation to represent sets of potentially correlated variables with principal components (PC) that are linearly uncorrelated and are ranked so that the first PC has the largest possible variance. Accordingly, the PCs with the largest variance are selected to represent the correlated variables, resulting in a smaller volume of data, eliminating intercorrelations, and maintaining the ability to retain the majority of the information contained in the data initially obtained (Kirkwood et al., 2011; Zhang & Castelló, 2017). In the biomechanics context, PCA has become a useful method for analyzing a set of temporal waveforms of human motion data (Brandon et al., 2013), and has been applied to the coordination of complex movement in different tasks of the upper (Mollazadeh et al., 2014) and lower limbs (Quan et al., 2021), population ages (Malloggi et al., 2021; Sadeghi et al., 2000), and conditions (Dillmann et al., 2014; Federolf et al., 2013; Milovanović & Popović, 2012). Moreover, age-related changes in neuromuscular control, kinematics, and muscle function during gait identified by PCA were previously not detected by motion analysis through discrete variables (Schloemer et al., 2017). Phinyomark et al., studying the biomechanical features of running gait data associated with iliotibial band syndrome, compared the results provided by discrete variables with the PCA. The authors suggest that care must be taken when selecting features of gait waveforms for both identification and discrimination of between-group differences for injured and non-injured runners (Phinyomark et al., 2016). Deluzio and Astephen first applied the PCA as a data reduction tool, as well as a preliminary step for further analysis to determine differences between the osteoarthritis and the control groups. The authors found that the discriminative features of the gait waveforms were the amplitude of the knee flexion moment, the range of motion of the knee flexion angle, the magnitude of the knee flexion moment during early stance, and the magnitude of the knee adduction moment during stance (Deluzio & Astephen, 2007).

Currently, to the best of our knowledge, only one review addressed the degree of freedom and dimensional properties of gait task and the application of the PCA in a non-structured review (Wang et al., 2013). However, it only addresses the gait task without specifying the population. Accordingly, this systematic review aims to synthesize current evidence regarding the study of the older adult's movement (kinematics and kinetics) according to a PCA, compared to younger adults, summarizing the tasks and biomechanical variables studied. As a secondary aim, the instruments used to assess the tasks and biomechanical variables will be reported.

2. Materials and Methods

This systematic review was carried out according to the Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement 2020 (Page et al., 2021), and was registered on the PROSPERO (International Prospective Register of Ongoing Systematic Reviews) platform with the registration number CRD42022329200 (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=329200, accessed on 23 October 2022).

2.1. Eligibility Criteria

According to the PICOS strategy, the criteria defined for inclusion of the studies were: population, older adults aged 60 years or over, living in the community; exposure, studies that applied the PCA in the biomechanical analysis of the movements of older adults; movement analysis associated with the aging process; comparator, young adults (less than 60 years); outcomes, tasks and biomechanical variables (kinematics and kinetics) and, if described, the instruments used to collect the biomechanical data; study design, observational studies (cross-sectional and longitudinal). As exclusion criteria, it was decided to exclude the studies if their participants were institutionalized (or if the data from institutionalized participants could not be separated from community-dwelling ones) or if the participants presented some major pathology with repercussions on the performance of movement, such as stroke or Parkinson disease (or if the data from participants with these conditions could not be separated from the complete study sample). The search was restricted to the studies published in the Portuguese and English languages, that were available in the last 20 years.

2.2. Selection and Data Collection Process

The studies were searched using three databases: MEDLINE (PubMed), Scopus and Web of Science. Specific search algorithms were elaborated for each database, as described in the Table 1 for Pubmed and for the other two databases in the supplementary material. Each concept was searched according to the database search instructions, using the MeSH terms and synonyms. Two reviewers independently assessed the studies' titles and abstracts in the identification phase. Then, in the screening phase, the same reviewers assessed the full texts. Disagreements about whether a study should be included were resolved if there was an oversight of information on the part of one of the reviewers or by discussion, consulting a third reviewer in the cases of different interpretation of studies content. The two reviewers used a pre-defined table to extract data from the included studies.

*Table 1: PICO framework strategy and search algorithm used in Medline (Pubmed) database. (*After a word, a truncation symbol (wildcard) to retrieve plurals or varying endings, # Truncation symbol for one character).*

PICOS	Keyword	Algorithm	Query
Population	Older Adults	"aged"[MeSH Terms] OR "aged"[Title/Abstract] OR "elder*" [Title/Abstract] OR "older adult*" [Title/Abstract] OR "aged, 80 and over" [MeSH Terms] OR "aged 80 and over"[Title/Abstract] OR "older person*"[Title/Abstract] OR "centenarian*"[MeSH Terms] OR "centenarian*"[Title/Abstract] OR "sexagenarian*" [Title/Abstract] OR "septuagenarian*" [Title/Abstract] OR "octogenarian*"[MeSH Terms] OR "octogenarian*" [Title/Abstract] OR "nonagenarian*"[MeSH Terms] OR "nonagenarian*"[Title/Abstract]	#1
Exposure	PCA	"Principal Component Analysis"[MeSH Terms] OR "Principal Component Analysis"[Title/Abstract] OR "PCA"[Title/Abstract]	#2
Comparison	Young Adults	Did not restrict the comparator	
Outcomes	Tasks and biomechanical variables (kinematics and kinetics)	"Movement"[MeSH Terms] OR "Movement"[Title/Abstract] OR "Musculoskeletal Physiological Phenomena"[MeSH Terms] OR "Musculoskeletal Physiological Phenomena"[Title/Abstract] OR "Biomechanical Phenomena"[MeSH Terms] OR "Biomechanical Phenomena"[Title/Abstract] OR "movement evaluation" [Title/Abstract] OR "kinematics"[Title/Abstract] OR "biomechanics"[Title/Abstract] OR "Task Performance and Analysis"[MeSH Terms] OR "Task Performance and Analysis"[Title/Abstract] OR "task"[Title/Abstract] OR "gait"[MeSH Terms] OR "gait"[Title/Abstract] OR "sit-to-stand" [Title/Abstract] OR "Kinetics"[MeSH Terms] OR "kinetic*" [Title/Abstract] OR "Stair Climbing"[MeSH Terms] OR "Stair Climbing"[Title/Abstract] OR "Walking"[MeSH Terms] OR "Walking"[Title/Abstract] OR "Exercise Test"[MeSH Terms] OR "Exercise Test"[Title/Abstract]	#3

Study design	Observational studies	"randomized controlled trial"[Publication Type] OR "randomized controlled trials as topic"[MeSH Terms] OR "randomized controlled trial"[Title/Abstract] OR "clinical trial"[Publication Type] OR "clinical trial"[Title/Abstract] OR "controlled clinical trial"[Publication Type] OR "controlled clinical trials as topic"[MeSH Terms] OR "controlled clinical trial"[Title/Abstract] OR "Comment"[Publication Type] OR "Letter"[Publication Type] OR "correspondence as topic"[MeSH Terms] OR "Editorial" [Publication Type] OR "Review"[Publication Type] OR "review literature as topic"[MeSH Terms] OR "Systematic review" [Publication Type] OR "Systematic reviews as topic"[MeSH Terms] OR "Systematic review"[Title/Abstract] OR "meta analysis"[Publication Type] OR "meta analysis as topic"[MeSH Terms] OR "meta analysis"[Title/Abstract] OR "meta analysis as topic"[MeSH Terms] OR "Guideline"[Publication Type] OR "Practice Guideline" [Publication Type] OR "Practice Guidelines as Topic" [MeSH Terms]	#4
Final Query		(#1 AND #2 AND #3) NOT #4	

2.3. Assessment of Methodologic Quality

The study design of the included studies is observational, and as there is no gold standard of risk of bias (ROB) tools for observational studies, different tools have been used in previous systematic reviews (Mamikutty et al., 2021). The most commonly used ROB tools are the Newcastle-Ottawa Scale (NOS) and the Downs & Black scale (Mamikutty et al., 2021). Downs & Black scale was found to be fairly comprehensive; easy to use and clear descriptions of how to score items (Deeks et al., 2003). The scale has good test-retest reliability (r = 0.88), good interobserver reliability (r = 0.75) and a high internal consistency (KR-20:0.89) (Black, 1998). Accordingly, it was decided to evaluate the ROB of articles included in this review by two reviewers. As in the previous processes, the differences between the two reviewers were solved by consulting a third reviewer. The Downs & Black instrument consists of 27 items that assess the quality of the study, including data reporting, external validity, internal validity (bias), internal validity (confounders) and power (Black, 1998). In this study, a modified version of the Downs & Black scale, adapted by Rollo et al., 2020, was used, in which the authors removed 10 items (8, 13–15, 17, 19, and 21–24) from the original scale, because they were considered not relevant for the analysis of observational studies. In addition, the authors modified the items (4, 5, 9, 26 and 27) and created two new items, one of which describes the criteria of internal validity and the other is related to the power of study (Rollo et al., 2020). The modified Downs & Black scale is then composed of 19 items, and the possible score on each item is 0 or 1. The maximum possible score is 19 points (all positive signs), with a higher score indicating higher quality (Rollo et al., 2020).

Scores were given corresponding quality levels: excellent (18–19), good (14–17), fair (10–13), or poor (≤9) (Hooper et al., 2008; Rollo et al., 2020).

3. Results

The initial search was completed on 12 May 2022. From the 1685 results obtained in the data search, 306 duplicates were removed and seven studies were retracted by the automated tools. After the screening and posterior full-text analysis, 19 studies (Aprigliano et al., 2017; Armstrong et al., 2021; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Gulde et al., 2019; Kobayashi et al., 2016; Liu et al., 2020; Paizis et al., 2008; Park et al., 2011; Reid et al., 2010; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002; Slaboda et al., 2011; Verrel et al., 2009; Wu et al., 2007; Zhou et al., 2020) were included in narrative analysis (Figure 1).

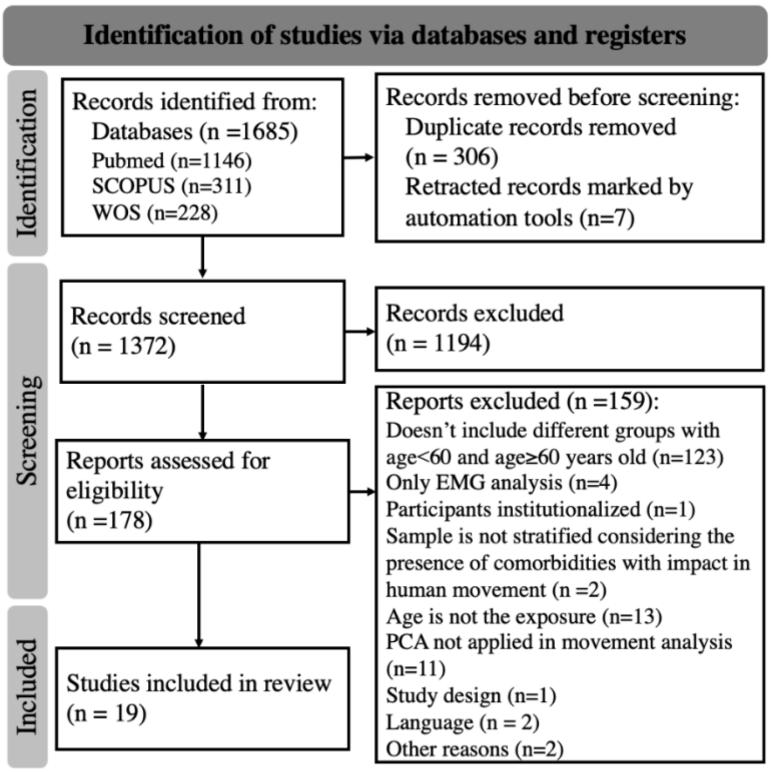

Figure 1: Systematic review PRISMA 2020 flow diagram.

3.1. Characterization of the Included Studies

The identification, main purpose and conclusions of the 19 included studies is presented in Table 2 The publication year of each study varied between 2002 (Sadeghi et al., 2002) and 2021 (Armstrong et al., 2021; Rowe et al., 2021), and out of the nineteen studies, eighteen were cross-sectional, and one classified themselves as a retrospective cohort (Boyer & Andriacchi, 2016). The study's sample size ranged from 14 (Park et al., 2011) to 239 (Zhou et al., 2020) participants, constituting a total of 1281 participants. The older group sample size ranged from seven (Park et al., 2011) to 127 (Zhou et al., 2020) participants. The mean age of the older adults group ranged from 63, 7 years old (Rowe et al., 2021) to 79, 43 years old (Park et al., 2011), while the younger groups' age ranged between 4.8 years (Bleyenheuft & Detrembleur, 2012) to 55,1 years old (Zhou et al., 2020) (Table 3). Six studies did not present any information regarding the gender of the participants (Aprigliano et al., 2017; de Freitas et al., 2010; Dewolf et al., 2019; Liu et al., 2020; Reid et al., 2010; Wu et al., 2007). The mean percentage of female participants was 56.9% across the studies that reported this information. Moreover, there was one study that only included participants of the male gender (Sadeghi et al., 2002), and one study that only included female participants (Slaboda et al., 2011).

Most of the included studies reported age-related differences between groups (*n* = 13) (Armstrong et al., 2021; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Gulde et al., 2019; Liu et al., 2020; Paizis et al., 2008; Park et al., 2011; Reid et al., 2010; Rosenblum et al., 2020; Slaboda et al., 2011; Wu et al., 2007; Zhou et al., 2020). To understand if age had effects on the balance and coordination of movement, six studies were carried out (Armstrong et al., 2021; de Freitas et al., 2010; Dewolf et al., 2019; Liu et al., 2020; Paizis et al., 2008; Slaboda et al., 2011). Two included studies focused on the study of upper limbs (Gulde et al., 2019; Park et al., 2011). Age-related differences were also reported by Boyer & Andriacchi, 2016 Reid et al., 2010, Rosenblum et al., 2020, Wu et al., 2007, and Zhou et al. 2020 when studying gait under different conditions. Also assessing gait under different conditions, five studies (Aprigliano et al., 2017; Bleyenheuft & Detrembleur, 2012; Rowe et al., 2021; Sadeghi et al., 2002; Verrel et al., 2009) found no age differences in intralimb coordination (Aprigliano et al., 2017), segmental covariation (Bleyenheuft & Detrembleur, 2012), overall gait strategy (Rowe et al., 2021), sagittal knee muscle moment curves (Sadeghi et al., 2002), and in the regularity of whole-body movements (Verrel et al., 2009).

Table 2: The identification, main purpose and conclusions of the included studies.

Study	Purpose	Conclusion
Aprigliano, et al. 2017 Italy	Assess how aging modifies intralimb coordination strategy during corrective responses during treadmill walking.	Intralimb coordination described by the planar covariation law was not affected by aging.
Armstrong, et al. 2021 Canada	Assess if the whole-body movement and/or motor control strategy differ as a function of age or sex in a forward reactive step to maintain balance.	PCA enabled to differentiate younger and older adults according to gender in terms of whole-body reactive stepping strategy and how ground reaction forces and kinetics support maintaining balance synergistically with whole-body movement strategy, when combined with multiple regression analysis.
Bleyenheuft & Detrembleur, 2012 Belgium	Assess the impact of age on kinematic segmental covariation at 3 different walking speeds.	The covariation remains stable between 15 and 70 years old.
Boyer & Andriacchi, 2016 United States of America (USA)	Assess the impact of age on knee function during walking in individuals with healthy knees as it applies to the development of knee osteoarthritis.	PCA analysis provided insight to the progressive changes in the magnitude of joint angles and in the kinematic coupling at the knee with age.
De Freitas et al., 2010 Brazil	Assess age-related effects on postural responses following forward support surface translation throughout middle-adulthood and early old age.	Independent of age, the individuals were able to minimize center of mass backward displacements in response to forward perturbation and to revert the direction of this displacement at proper time with similar kinematics patterns. However, after the fifth decade changes in neuromuscular responses are observed.
Dewolf et al., 2019 Belgium	Assess the effects of age on the intersegmental coordination in healthy young and elderly adults walking at matched speeds.	Older adults present decreased intersegment covariation with speed compared to young adults, mainly related to foot-shank coordination.
Gulde et al., 2019 Germany	Assess the effects of speed of execution on upper-limb kinematics, in activities of daily living, with respect to age.	PCA revealed a movement strategy and age-dependent decline in primarily executive functions.
Kobayashi et al., 2016 Japan	Assess age independent and most dominant sex differences observed in gait during normal walking.	PCA was able to identify a variation with significant age-sex interaction and another with significant sex difference but no age-effect or age-sex interaction.
Liu et al., 2020 Taiwan	Assess the coordination of the multiple joints of the human body to maintain a stable posture and how it varies with age.	Aging increases the coupling strength and decreases the changing speed and the complexity of inter-joint coordination patterns.

Paizis et al., 2008 France	To understand equilibrium function and movement coordination in elderly by means of a whole-body goal-oriented task.	During whole-body movements, center of mass displacements are smaller in elderly compared to young adults and this postural aging effect is associated with straighter wrist paths. Despite these changes, high covariations of joint and elevation angles, observed in young adults, were also preserved in older adults.
Park et al., 2011 USA	Assess age-related changes in finger coordination during accurate force and moment of force production tasks	The magnitudes of the loading coefficients in the PC analysis suggested that the young subjects used mechanical advantage to produce moment while elderly subjects did not.
Reid et al., 2010 Canada	To use PCA to compare the gait patterns between young and older adults during stair climbing	The PCA and discriminant function analysis identified gait pattern differences between young and older adults.
Rosenblum et al., 2020 Israel	To calculate total recovery time after different types of perturbations during walking and use it to compare young and older adults following different types of perturbations.	PCA showed differences in step length and step width recovery times between AP and ML perturbations.
Rowe et al., 2021 Canada	To examine and describe age and sex-specific temporal pattern differences in lower extremity gait mechanics in asymptomatic adults.	The use of PCA enabled the observation of major sex-specific differences leading to the identification of an overall difference in walking gait strategy between healthy adult male and female participants, independent of age.
Sadeghi et al., 2002 Canada	To identify the main structural characteristics of the sagittal knee muscle moment curves developed in elderly and young able-bodied subjects	No significant differences were found between groups about the quality or magnitude of the sagittal knee peak muscle moment during the stance phase and early swing phase
Slaboda, J. C., 2011 USA	To explore the influence of continuous visual flow, during and following a postural disturbance (i.e., support surface tilt), on the ability to reorient to vertical.	The fPCA revealed greatest mathematical differences in center of mass and center of pressure responses between groups or conditions during the period that the platform transitioned from the sustained tilt to a return to neutral position
Verrel et al., 2009 Germany	To investigate the effects of concurrent cognitive task difficulty (n-back) on the regularity of whole-body movements during treadmill walking in women and men from 3 age groups.	Age seems to not influence gait regularity.
Wu et al., 2007 China	To evaluate the use of Kernel-based Principal Component Analysis to extract more gait features (i.e., to obtain more significant amounts of information about human movement) and improve the classification of gait patterns.	Nonlinear gait features can be extracted to automatic classification of healthy young or older adults gait patterns.

Zhou et al., 2020 Netherlands	To evaluate if different groups (healthy young-middle aged adults, healthy older adults, and geriatric patients) can be classified based on dynamic outcomes.	The following dynamic gait outcomes are important for classifying the three groups: regularity (vertical direction), stability (maximal Lyapunov exponent of the vertical acceleration) and pace (gait speed and the variability of the accelerations (RMS) in anterior-posterior and vertical direction).

*Table 3: Included studies' characterization, specifically, the study identification, sample size, mean age, and percentage of females, the tasks, variables, instruments and description of the PCA use in the study. * CM, centre of mass; CoP, centre of pressure; F, female; Total normal force, FTOT; Moment of normal force, MTOT; GRF, ground reaction force; M, male; MAG, middle aged adults; OG, older group; RG, retiree/geriatric group; ROM, range of motion; SD, standard deviation; y, years; YG, young group.*

Study	Participants (*n*) Females (%) Age (Mean ± SD)	Tasks	Variables	Instruments	PCA in Data Processing and/or Analysis
Aprigliano, et al. 2017	20 10 YG 24.4 ± 2.5 10 OG 66.3 ± 5.1	Treadmill gait with and without perturbations	Spatio-temporal parameters: stride duration; stance phase duration; step length; step width Range of Motion (ROM): Hip; Knee; Ankle Intralimb coordination	Optoelectronic system -Vicon Motion Analysis System (Oxford, UK) -6 cameras	PCA was used to assess intralimb coordination calculated through the relationship among elevation angles (planar covariation law).
Armstrong, et al. 2021	80, 56, 25% 40 YG M 23.0 ± 2.8; F 22.3 ± 3.7 40 OG M 71.6 ± 3.7 F 68.3 ± 4.2	Hip and knee maximal isometric contraction; Stepping.	Strength: Hip flexion, extension and abduction -Knee extension; Marker trajectory; Voluntary reaction time; Ground reaction forces (GRF)	Uni-axial load cell -MLP-300-CO, Transducer Techniques, Temecula, CA. Optoelectronic system: -Optotrak Certus, NDI (Waterloo, ON, Canada). Force platform: OR6-7, Advanced Mechanical Technology Incorporated, USA	PCA was used to reduce the dimensionality of time-series, marker trajectory data captured to represent whole-body stepping responses.
Bleyenheuft & Detrembleur, 2012	30 6 5 y: 4.8 ± 0.4, 83% 6 10 y 9.3 ± 0.5, 50%F 6 15 14.3 ± 0.5, 100% 6 20 y 23.5 ± 2.9, 100% 6 70 y 77.3 ± 5.0, 50%	Treadmill gait at 3 different speeds: 1 km h−1, 3 km h−1, and 5 km h−1,	ROM: thigh, shank and foot elevation angles; Mechanics and energetics Mechanical power Energetic cost	Optoelectronic system: -ELITE system -6 cameras Ergospirometer (Cosmed, Rome, Italy)	PCA was used to describe the covariation between thigh, shank and foot elevation angles.

Boyer & Andriacchi, 2016	74 25 YG 24 ± 2.3, 44% 25 MAG 48 ± 4.7, 48% 24 OG 64 ± 2.4, 54%	Overground gait at self-selected speed	ROM: knee flexion, ab-adduction and internal-external rotation angles; Anterior-posterior translation of the tibia with respect to the femur forces GRF	Optoelectronic system: -ProReflex, Qualysis Inc, Sweden -8 cameras Force platform: -Bertec Corporation, Columbus, OH, USA	PCA was used to characterize and statistically compare the patterns of joint movement and identifying interactions between the three components of joint rotation and the translation.
de Freitas et al., 2010	36 9 20–25 y 9 40–45 y 9 50–55 y 9 60–65 y	stand on the platform to evaluate the participants' postural reactions to temporally unpredictable perturbations	ROM: ankle, knee, and hip Maximum backward displacement of body center of mass (CM) time-to-reversal of body CM	Optoelectronic system: -Optotrak (Digital Northern, Inc.).	PCA was performed on the linear covariation of ankle, knee, and hip joint angles to estimate the postural synergies [i.e., the coupling among the joints involved in the postural task] employed to minimize the CM horizontal displacement
Dewolf et al., 2019	26 8 YG 24.5 ± 2.4 18 OG 75.6 ± 6.7	treadmill gait at 6 different selected speeds (0.56, 0.83, 1.11, 1.39, 1.67 and 1.94 m s−1)	GRF ROM: hip, knee, and ankle) Spatiotemporal parameters: Stride length	Modified commercial treadmill -h/p/ComosStellar, Germany -4 force transducers (Arsalis, Belgium). Optoelectronic system: high-speed video camera (BASLER piA 640-210).	PCA was applied to determine the covariance matrix of the hip, knee and ankle elevation angles
Gulde et al., 2019	64 26 YG 22.31 ± 2.13, 58% 16 OG 63.06 ± 2.43, 50% 22 RG 71.27 ± 3.48, 50%	To prepare a cup of instant ice-tea or to prepare a letter to be sent and performed at a natural speed or as fast as possible.	Spatiotemporal parameters: trial duration, relative activity, path length, relative vertical path length, mean peak velocity, number of velocity peaks per meter, bimanual cooperation, and quotient, bimanual velocity ratio	Optoelectronic system: -Qualisys Inc., Gothenburg, Sweden -7 cameras	PCA was used to extract the underlying relationship between age, activities of daily living performance, executive functions (trail making tasks), and fine motor control (Nine-Hole Peg Tests)

Kobayashi et al., 2016	191 67 YG 27.21 ± 5.37, 54% 43 MAG 52.74 ± 7.55, 49% 81 OG 68.01 ± 2.82, 43%	overground gait at comfortable, self-selected speed	ROM pelvic, right hip, knee, and ankle Spatiotemporal parameters: walking speed, step length, step width, stance time, swing time GRF	Optoelectronic system: -3D motion capture system (VICON) Force platform: -Force plates (BP400600-2000PT, AMTI)	PCA was used to identify the most dominant age independent sex differences in gaits during normal gait
Liu et al., 2020	45 15 YG 24.06 ± 2.02 30 OG 71.13 ± 4.56	standing still in a comfortable stance for 40 s.	Joint velocity signals: Mediolateral signals of the joints' center	Optoelectronic system: - Microsoft Kinect V2 sensor - Five-point stencil	PCA was performed on the joint velocity vectors for each experimental trial to quantify the complexity of inter-joint coordination pattern from a global perspective
Paizis et al., 2008	16 8 YG 23 ± 1.51, 50% 8 OG 74.5 ± 4.5, 50%	From standing posture, participants were requested to make a whole-body movement in the sagittal plane to grasp a wooden dowel placed at ground level in front of them.	Spatiotemporal parameters: movement duration, peak velocity, path displacement, path deviation from straightness, path curvature Position of the center of pressure (CoP) Amplitude of the CoP displacement and backward direction GRF	Optoelectronic system: -SMART (BTS, Milan) -5 cameras Force Platform: AMTI (Advanced Mechanical Technology Inc., Watertown, MA)	PCA was performed to evaluate the whole-body movement coordination. To account for different motor strategies separate PCA were performed for each participant and for each condition
Park et al., 2011	14 7 YG 29.86 ± 2.27, 71% 7 OG: 79.43 ± 4.31, 43%	Maximal voluntary contraction tasks and accurate force–moment production tasks, performed by the index finger and by four fingers pressing together	Strength: total normal force (FTOT) and moment of normal force (MTOT)	Force sensors: -Nano-17, ATI Industrial Automation, Garner, NC	PCA was performed on the finger force data which covered a broad range of FTTOT and MTOT combinations

Reid et al., 2010	62 30 YG 23.9 ± 2.6 32 OG 65.5 ± 5.2	Stair climbing	ROM Knee Flexion, Internal rotation, Adduction Posterior–anterior, Lateral–medial, Distal–proximal force Flexion, Internal rotation moment net forces and net reaction moments at the knee	Optoelectronic system: Optotrak 3020 (Northern, Digital, Waterloo, Canada) Force platform: Force plate (AMTI, Newton, MA, USA)	PCA was used to reduce the size of the data set. PCs were created for the knee joint moment, angle, and force curves about the three axes
Rosenblum et al., 2020	24 12 YG 26.92 ± 3.40, 71% 12 OG 66.83 ± 1.60, 50%	treadmill gait with medio-lateral (ML) or anterior-posterior (AP) perturbations	Spatiotemporal parameters -step length, step width, total recovery time	Optoelectronic system: -Motek-Medical, the Netherlands Force plates: Zemic load cells; The Netherlands	PCA was used to explore the effects of perturbation direction on total recovery times, applying the singular value decomposition
Rowe et al., 2021	154 38 20-40y: 34.7 ± 5.9, 66% 45 41-50y: 46.2 ± 2.7, 67% 47 51-59y 55.1 ± 2.6, 64% 24 60 + Y 63.7 ± 3.5, 38%	overground gait in self-selected speed	ROM ankle, knee and hip) Spatiotemporal parameters: walking speed, stride length, stance time GRF	Optoelectronic system: Optotrak motion capture system (Northern Digital, Inc.) Force platform: force platform (AMTI, Watertown, MA, USA).	PCA was applied to extract major patterns of variability from hip, knee and ankle joint angles and net external moments
Sadeghi et al., 2002	40, 0% 20 YG 25 ± 8.1 20 OG 72 ± 5.5	overground gait at self-selected pace	Spatiotemporal parameters: speed, stance phase, stride length, cadence GRF	Optoelectronic System Motion Analysis system (YG) Optotrak (OG) Force plates AMTI	PCA was applied as a classification and data structure detection method to the sagittal knee muscle moment curves of the elderly and young subjects
Slaboda, J. C., 2011	28, 100% 14 YG (20–39) 14 OG (60–79)	Standing in the upright position in the dark while different tilts were applied to the platform	COP CM ROM ankle and hip	Force platform -AMTI, Watertown, MA. Optoelectronic System Motion Analysis (Santa Rosa, CA, USA) 6 cameras	Functional PCA was applied to CM, COP, segmental angles, and IMNF (instantaneous mean frequency curve) data to identify trial periods in which the two populations were differentially affected by visual conditions

Verrel et al., 2009	96 32 20–30y, 50% 32 60–70y, 50% 32 70–80y, 50%	overground gait at a fixed speed (2.5 km/hr.) and self-selected speed while dual tasking	Spatiotemporal parameters: Stride frequency, Step cycle Marker trajectory	Optoelectronic System: motion (Vicon 612, Workstation 4.6; Vicon Ltd., Oxford, UK) 12 cameras (infrared V-cam 100 & 200)	The PCA was used to assess gait regularity based on the split of marker trajectory into residual and main components
Wu et al., 2007	48 24 YG 25.10 ± 5.3 24 OG 74.6 ± 2.55	overground gait at a self-selected speed	Spatiotemporal parameters: Stride length, Stride duration, Gait velocity, Single support duration, stance duration, Swing duration, Gait cadence ROM: Hip, knee and ankle	Optoelectronic System: OptoTrak 3020 motion analysis system (Northern Digital Inc., Waterloo, Canada).	The PCA and KPCA were used to extract nonlinear features from spatiotemporal and kinematic gait data for automatic classification of healthy young or older adults gait patterns
Zhou et al., 2020	239 57 MAG 42.72 ± 16.6, 47% 55 OG 74.58 ± 5.71, 36% 127 RG 79.3 ± 5.81 51%	overground gait	Spatiotemporal parameters: Speed, gait step or stride regularity, Root Mean Square, Smoothness: Index of Harmonicity, symmetry, multiscale Entropy, Cross-sample Entropy, frequency variability, maximal Lyapunov exponent	iPod Touch G4 (iOS 6; Apple Inc.) accelerometer unit: DynaPort hybrid unit (McRoberts BV, Te Hague, The Netherlands)	The PCA and KPCA were used to reduce the dimensionality of calculated outcomes while preserving the informative and variability properties

3.2. Tasks Assessed in Included Studies

Eleven studies assessed the gait task. Five studies assessed the task in treadmill under perturbed conditions (Aprigliano et al., 2017; Rosenblum et al., 2020), different speeds (Bleyenheuft & Detrembleur, 2012; Dewolf et al., 2019), and dual tasking (Verrel et al., 2009), while the other six studies assessed the overground gait (Boyer & Andriacchi, 2016; Kobayashi et al., 2016; Rowe et al., 2021; Sadeghi et al., 2002; Wu et al., 2007; Zhou et al., 2020). Three studies assessed upright standing in unperturbed (Liu et al., 2020) and perturbed conditions (de Freitas et al., 2010; Slaboda et al., 2011). The remaining five articles assessed different tasks, such as stepping (Armstrong et al., 2021), preparing a cup of tea and a letter (Gulde et al., 2019), grasping an object placed at the ground from a standing position (Paizis et al., 2008), climbing stairs (Reid et al., 2010), and during maximal voluntary contraction of fingers (Park et al., 2011) (Figure 2).

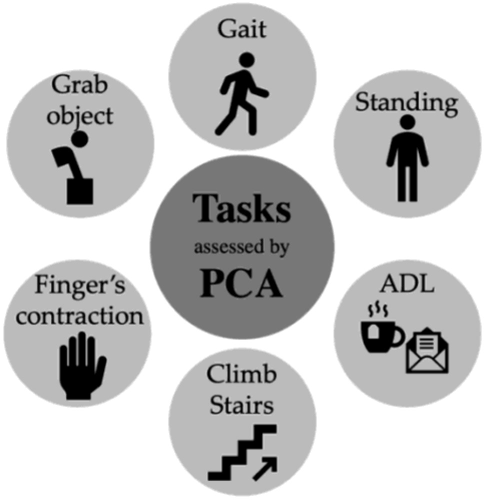

Figure 2: Summary of the older adults movement tasks analyzed and processed by PCA (ADL: Activity of daily living; PCA: Principal component analysis).

3.3. Variables Assessed in Included Studies

The spatial-temporal parameters (Aprigliano et al., 2017; Dewolf et al., 2019; Gulde et al., 2019; Kobayashi et al., 2016; Paizis et al., 2008; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002; Verrel et al., 2009; Wu et al., 2007; Zhou et al., 2020), the range of motion (ROM) of lower limbs joints (Aprigliano et al., 2017; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Kobayashi et al., 2016; Reid et al., 2010; Rowe et al., 2021; Slaboda et al., 2011; Wu et al., 2007), and the ground reaction forces (GRF) (Armstrong et al., 2021; Boyer & Andriacchi, 2016; Dewolf et al., 2019; Kobayashi et al., 2016; Paizis et al., 2008; Rowe

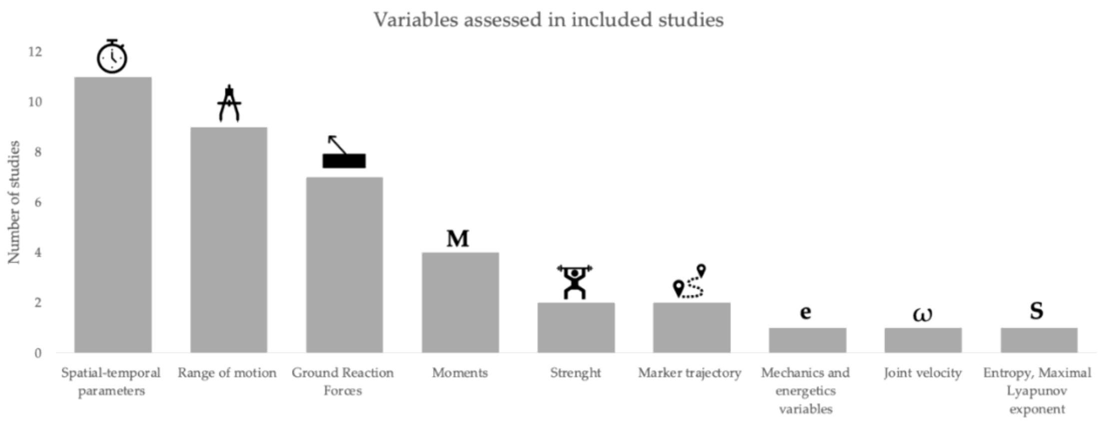

Figure 3: Summary of the older adults movement variables processed by PCA.

et al., 2021; Sadeghi et al., 2002) were the most assessed variables (Figure 3). Beyond these three variables the following variables have also been considered: calculation of moment (Paizis et al., 2008; Park et al., 2011; Sadeghi et al., 2002), strength related variables (Armstrong et al., 2021; Park et al., 2011; Reid et al., 2010), center of mass (CM) (de Freitas et al., 2010; Slaboda et al., 2011), center of pressure (CoP) (Paizis et al., 2008; Slaboda et al., 2011), marker trajectory (Armstrong et al., 2021; Verrel et al., 2009); mechanics and energetics variables (Bleyenheuft & Detrembleur, 2012), joint velocity (Liu et al., 2020); and multi scale entropy, cross-sample entropy, frequency variability, and maximal Lyapunov exponent (Zhou et al., 2020).

3.4. Movement Analysis Instruments

For the movement capture and analysis, optoelectronic systems were used in all articles except two (Park et al., 2011; Zhou et al., 2020), where an inertial system (Zhou et al., 2020) and force plates were used (Park et al., 2011). Among the seventeen studies that used optoelectronic systems, eight described the number of cameras used for capturing the movement (Aprigliano et al., 2017; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; Dewolf et al., 2019; Gulde et al., 2019; Paizis et al., 2008; Slaboda et al., 2011; Verrel et al., 2009). The number of cameras used ranged from one (Dewolf et al., 2019) to twelve (Verrel et al., 2009). Force platforms were used in ten of the studies (Armstrong et al., 2021; Boyer & Andriacchi, 2016; Dewolf et al., 2019; Kobayashi et al., 2016; Paizis et al., 2008; Reid et al., 2010; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002; Slaboda et al., 2011), in which six were studies that assessed gait (Boyer & Andriacchi, 2016; Dewolf et al., 2019; Kobayashi et al., 2016; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002) and the other four were related to stepping (Armstrong et al., 2021), stair climbing (Reid et al., 2010), and standing in the upright position (Paizis et al., 2008; Slaboda et al., 2011).

3.5. The Use of PCA in Data Processing and/or Analysis

PCA was applied to extract features from several waveforms data (Aprigliano et al., 2017; Armstrong et al., 2021; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Gulde et al., 2019; Kobayashi et al., 2016; Liu et al., 2020; Paizis et al., 2008; Park et al., 2011; Reid et al., 2010; Rosenblum et al., 2020;

Rowe et al., 2021; Sadeghi et al., 2002; Verrel et al., 2009). The functional PCA was used in one of the included studies to produce a measure of variability across an entire curve captured as a small subset of functional principal components (Slaboda et al., 2011), and Kernel-based PCA was used in two studies, in one for nonlinear feature extraction and the evaluation of its effect on a subsequent classification in combination with learning algorithms (support vector machines) (Wu et al., 2007), and in the other for dimensionality data reduction for support vector machine classification (Zhou et al., 2020).

3.6. Methodological Quality Assessment

The methodological quality assessment score, according to the Downs & Black scale, ranged from ten (Aprigliano et al., 2017; de Freitas et al., 2010) to 16 (Rowe et al., 2021) and is presented in Table 4. The average score of the articles included is approximately 12.79 points, the *fair* level. Seven studies (Armstrong et al., 2021; Boyer & Andriacchi, 2016; Kobayashi et al., 2016; Reid et al., 2010; Rosenblum et al., 2020; Rowe et al., 2021; Verrel et al., 2009) (36.8%) obtained a good classification and the remaining twelve (63.2%) obtained a fair classification. In general, the articles revealed very similar "Reporting" and "Internal validity" values, but only one scored in the "Power" section, while none scored in the "External validity" section.

Table 4: Methodological quality assessment according to modified Downs & Black scale.

	Modified Downs & Black Scale Items																			
Study ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Total**
Aprigliano, et al., 2017	1	1	0	0	0	1	1	1	0	0	0	1	0	1	1	1	1	0	0	10
Armstrong, et al., 2021	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	14
Bleyenheuft & Detrembleur, 2012	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	1	0	0	11
Boyer & Andriacchi., 2016	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	15
de Freitas et al., 2010	1	1	0	0	0	1	1	1	0	0	0	1	1	1	1	0	1	0	0	10
Dewolf et al., 2019	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	0	1	0	0	11
Gulde et al., 2019	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	13
Kobayashi et al., 2016	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	14
Liu et al., 2020	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	13
Paizis et al., 2008	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	12
Park et al., 2011	1	1	1	0	0	1	1	1	0	0	0	1	1	1	1	0	1	0	0	11
Reid et al., 2010	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	14
Rosenblum et al., 2020	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	14
Rowe et al., 2021	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	16
Sadeghi et al., 2002	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	13
Slaboda, J. C., 2011	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	13
Verrel et al., 2009	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	14
Wu et al., 2007	1	1	1	0	1	1	1	1	UD	0	0	1	1	1	1	1	1	0	0	13
Zhou et al., 2020	1	1	1	0	1	1	1	1	0	0	0	1	0	1	1	1	1	0	0	12

4. Discussion

This systematic review aimed to summarize the tasks and biomechanical variables studied when PCA was applied in the study of the older adult population's movement compared with younger adults. The results of the systematic search reinforce the need to gather this information as this method has been widely used, mainly in Europe (n = 7) and North America (n = 8), and more than half of the included studies (n = 11) were published in the last decade.

The study's sample size ranged from 14 (Park et al., 2011) to 239 (Zhou et al., 2020) participants. In the literature, there is no agreement over the recommended sample size for the use of PCA, and the ratio between sample size and variables assessed. Guadagnoli and Velicer indicated that absolute minimum sample sizes, rather sample sizes as a function of the number of variables, are more relevant (Guadagnoli & Velicer, 1988). More recently, Osborne and Costello stated that both should be taken into consideration to avoid errors of interference, indicating that the best outcomes occur in analyses where large numbers of sample size and high ratios are present (Osborne & Costello, 2004). Because there is no simple method for calculating sample size in PCA (Saccenti &

Timmerman, 2016), Comfrey and Lee (1992) cited by Osborne and Costello (Osborne & Costello, 2004) suggested that "the adequacy of sample size might be evaluated very roughly on the following scale: 50–very poor; 100–poor; 200–fair; 300–good; 500–very good; 1000 or more–excellent". In the present review, 11 of the 19 articles included have fewer than 50 participants, so interpretation of their results should take that into consideration.

The most assessed task was the gait, with five studies assessing the task on a treadmill (Aprigliano et al., 2017; Bleyenheuft & Detrembleur, 2012; Dewolf et al., 2019; Rosenblum et al., 2020; Verrel et al., 2009), while the other six studies assessed the overground gait (Boyer & Andriacchi, 2016; Kobayashi et al., 2016; Rowe et al., 2021; Sadeghi et al., 2002; Wu et al., 2007; Zhou et al., 2020). Older adults' mobility can be influenced by multiple physiological and psychological factors (Soubra et al., 2019), and other tasks as the balance should be assessed considering that its integrity is essential for activities of daily living efficacy (Nnodim & Yung, 2015). Accordingly, only three studies assessed upright standing (de Freitas et al., 2010; Liu et al., 2020; Slaboda et al., 2011), all expressing promising results. Other activities, such as stair descent, which is regarded as one of the most difficult activities for older adults (Singhal et al., 2014), are important to be assessed and processed in a broader context. In this review, only one study aimed to compare the gait patterns between young and older adults during stair climbing (Reid et al., 2010). Therefore, there is a need to explore other tasks with the PCA approach. There are other activities, such as complex upper extremity-based manual activities of daily living tasks, in this review only assessed by Gulde et al. (Gulde et al., 2019) which are still pending movement analyses based on kinematic markers (Schmidle et al., 2022), and consequently exploration by multivariate analysis.

Because gait was the most assessed task, the most assessed variables were related to the spatial-temporal parameters (Aprigliano et al., 2017; Dewolf et al., 2019; Gulde et al., 2019; Kobayashi et al., 2016; Paizis et al., 2008; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002; Verrel et al., 2009; Wu et al., 2007; Zhou et al., 2020), and the ROM of lower limbs joints (Aprigliano et al., 2017; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Kobayashi et al., 2016; Reid et al., 2010; Rowe et al., 2021; Slaboda et al., 2011; Wu et al., 2007). However, as stated by Richards, in gait, for example, the knee angular velocity has been shown to exhibit more sensitivity than the knee flexion angles and timing parameters alone (Richards, 2018). As the joint angular velocity was only assessed by Liu et al. (Liu et al., 2020), it is necessary to explore different variables to better comprehend gait differences between older and younger adults.

PCA reduces the volume of data to a smaller number, and the visualization and statistical analysis of the new variables created, the principal components, can help to find similarities and differences between samples (Groth et al., 2013; Kirkwood et al., 2011). PCA was applied to extract features from several waveforms data (Aprigliano et al., 2017; Armstrong et al., 2021; Bleyenheuft & Detrembleur, 2012; Boyer & Andriacchi, 2016; de Freitas et al., 2010; Dewolf et al., 2019; Gulde et al., 2019; Kobayashi et al., 2016; Liu et al., 2020; Paizis et al., 2008; Park et al., 2011; Reid et al., 2010; Rosenblum et al., 2020; Rowe et al., 2021; Sadeghi et al., 2002; Verrel et al., 2009). In particular, PCA was used to analyze the angular covariance of the lower limb joints (Bleyenheuft & Detrembleur, 2012; de Freitas et al., 2010; Dewolf et al., 2019), extract space-time and kinematic data from gait (Boyer & Andriacchi, 2016; Rowe et al., 2021), reduce the size of the data (Armstrong et al., 2021; Reid et al., 2010), and to assess motor coordination (Aprigliano et al., 2017; Gulde et al., 2019; Liu et al., 2020; Paizis et al., 2008; Verrel et al., 2009). Additionally, the potential for PCA to uncover differences between groups was highlighted in three studies (Kobayashi et al., 2016; Rosenblum et al., 2020; Sadeghi et al., 2002). Accordingly, different applications of PCA were used within the included studies. Other studies used PCA variations, including functional PCA(Slaboda et al., 2011), and Kernel-based PCA (Wu et al., 2007; Zhou et al., 2020). Several included studies reported findings that were not possible by discrete analysis. Therefore, there is a need for the application of PCA in other tasks to understand older adult movement characteristics that have not been identified by discrete analysis. Cumbes and Azema proposed using the PCA to find feature patterns related to the autonomy–disability level, assessed by a disability scale, of elderly persons living in nursing homes (Combes & Azema, 2013). In a longitudinal study, Shin et al. aimed to group diseases classified by the International Classification of Diseases using the PCA to extract comorbidity patterns and found that the principal component 1, which included diabetes, heart disease, and hypertension, was associated with an increased hazard ratio of mortality (Shin et al., 2020). Some authors have already studied the kinematics of gait to cluster older adults with and without specific conditions (Deluzio & Astephen, 2007; Lukšys et al., 2018; Tsuchida et al., 2022). The PCA clustering could be applied to kinematic and kinetic data of different daily performance tasks of community-dwelling older adults to cluster the autonomy–disability level and mortality. Early identification of those with disabilities and/or specific conditions could allow the introduction of prevention programs promoting older adults' independence.

The results of this systematic review should be analyzed considering that three databases were searched. However, the three databases chosen include a broader range of indexed studies. Another limitation of this review may be the lack of inclusion of studies in languages other than English and Portuguese. A wider language criterion could increase the number of included studies as multivariate analysis has been used worldwide.

Taking into account that the vast majority of studies applied PCA to the analysis of tasks such as gait, as stated previously, it is necessary to develop studies that would investigate other tasks, including other daily life activities. In the upcoming studies, it is also necessary to include larger sample sizes in order to fully take advantage of the potential of multivariate analysis. Furthermore, other structured reviews and meta-analyses aiming to understand the role of PCA in the biomechanical analysis of older adults, differentiating between individuals with diseases or conditions and healthy ones (Deluzio & Astephen, 2007; Lukšys et al., 2018; Tsuchida et al., 2022), would be beneficial, as the evidence in these topics grows.

5. Conclusions

The aim of this systematic review was to gather the current information related to the use of the PCA method in the study of movement in the older adult population. Accordingly, PCA has been applied globally, mainly in the study of gait and orthostatic position. The main variables assessed were spatiotemporal parameters, the range of motion of lower limb joints, and ground reaction forces. PCA was mostly used to analyze the angular covariance of the lower limb joints, extract space-time and kinematic data from gait, reduce the size of the data, and assess motor coordination. A limited number of studies analyzed other tasks. Therefore, considering the potential of multivariate analysis, further research should focus on the PCA application in tasks other than gait to understand older adults' movement characteristics that have not been identified by discrete analysis.

Supplementary Materials (Appendix XIII):: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/s23010205/s1. Figure S1: Specific search algorithm for Scopus; Figure S2: Specific search algorithm for Web of Science; Figure S3: Specific search algorithm for Pubmed.

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Study III – Methodological considerations for older adult's movement analysis: a scoping review

Submitted to a scientific journal

ABSTRACT

Objective: This review aimed to consolidate existing guidelines regarding the kinematic assessment of older adults, focusing on the types of motor tasks to be monitored, the suitability of motion capture devices, and the evaluation of kinematic and kinetic metrics.
Materials and Methods: The PRISMA (scoping reviews) recommendations were followed, with searches conducted across the PubMed, Web of Science, and SCOPUS databases. Studies were included if provided guidelines for evaluating older adults' movement, specified motion capture systems utilized, and identified the kinematic metrics essential for analysing the movements of this demographic. Data were systematically extracted from the selected studies using a standardized data extraction table, including information about participant demographics, task types, motion capture systems employed, kinematic or kinetic metrics analysed, and the recommendations made.
Results: Five studies met the inclusion criteria with guidelines for assessing gait spatiotemporal parameters, primarily through electronic walkways use. The guidelines articulated considerations related to demographic and clinical characteristics, gait parameters, environmental and safety concerns, as well as criteria for reliability and comparability, reliability and comparability purposes; calculation, reporting, and interpretation parameters.
Conclusion: Current guidelines predominantly emphasize the spatiotemporal parameters of gait, computed by various motion capture systems. Future research should expand these guidelines to encompass a broader range of tasks and refine methodological considerations.

Keywords: Biomechanics, Aging, Guidelines, Methods

1. Introduction

The assessment of age-associated changes in structural and functional properties of musculoskeletal tissues have been performed in clinical and research contexts through the performance of different tasks and collection of different metrics. The stair ascent and descent (Novak & Brouwer, 2011; Reid et al., 2010), step (Wang et al., 2003) sit-to-stand (Kuo et al., 2010), sit-to-walk (Buckley et al., 2009) but more frequently gait performance (Herssens et al., 2018; Marques et al., 2018) have been explored to analyse older adults performance. Among different metrics considered, a decrease in older adults gait speed (Herssens et al., 2018) has been associated with different fall risk factors (Kyrdalen et al., 2019) (Marques et al., 2018), survival (S. Studenski et al., 2011), and even classified as a functional vital sign (Middleton et al., 2015). Other gait spatiotemporal parameters such as cadence, and step and stride length (Herssens et al., 2018), and joint range of movement differences in stair climbing patterns between older and young adults (Reid et al., 2010) have been explored. Some of these have been associated to the development of specific pathologies such as neurodegenerative conditions (Buckley et al., 2019).

In the clinical context, these assessments are primarily based on the observational analysis conducted by health professionals, complemented by additional clinical evaluations such as cranial nerve function, muscle strength, sensation, and deep tendon reflexes (Lee et al., 2014; Verghese et al., 2006). In laboratorial, a more objective movement analysis can be implemented by several methods comprising electrogoniometry, accelerometry, electromagnetic tracking devices, and imaging techniques (Photography, Cinematography, Videography, Optoelectronics) (Neumann, 2010). Nowadays, the optoelectronic system has become the laboratory gold standard for movement analysis (Cuesta-Vargas et al., 2010; Neumann, 2010). This method allows flexibility of movement, once the subject is unrestricted by wires or other devices, and versatility of movement, allowing to analyse from small motor tasks to human functional activities (Cuesta-Vargas et al., 2010; Neumann, 2010). However, these systems are mainly used in laboratories, and options like inertial measurement units allow objective assessment, remote monitoring, and support in ambient assisted living (Kim et al., 2022; Montesinos et al., 2018; Read et al., 2022).

However, despite these enormous achievements, there seems to exist a great variability in how the data from older adults' movement research is being collected and analysed, which compromises the comparison of studies considering movement analysis in older adults. To overcome this challenge, systematic reviews have summarized useful information to guide methodological decisions in movement assessment (Couto et al., 2022; Mesquita, Fonseca, et al., 2019; Mesquita, Pinheiro, et al., 2019; Parel et al., 2016). However, while some only consider specific tasks and pathologies, as stroke (Couto et al., 2022; Mesquita, Fonseca, et al., 2019; Mesquita, Pinheiro, et al., 2019), other only consider the assessment of specific body regions, as shoulder complex (Parel et al., 2016). Moreover, some guidelines have been stated for general population as the ones defined by the International Society of Biomechanics for biomechanical movement analysis (Biomechanics, 2020), and by the Italian Society of Clinical Movement Analysis, SIAMOC (Benedetti et al., 2017) for gait analysis. However, despite providing a comprehensive knowledge and recommendations for movement assessment, from data collection to data processing, these guidelines do not consider the features of older adult's population. More recently, some guidelines have been stated for movement analysis in older adults, namely for gait analysis (Beauchet et al., 2017). According to our knowledge, no study as gathered the existing guidelines for movement analysis specific for older adults to support the methodological decision-making process for data collection, including which system is more suited and the tasks that should be assessed. This gathering is essential for the development of scientifically robust and comparable protocols between studies, ensuring comparability of findings and results.

Based on the exposed, this review aims to gather guidelines for older adults' movement assessment, including the motor tasks that should be considered, motion capture systems used, and kinematic and kinetic metrics studied. In particularly, four main questions rose from the main objective:

What are the guidelines that should be considered when assessing older adult's movement?

What are the motor tasks that should be assessed to characterize older adult's movement?

What are the motion capture systems that should be used to analyse the older adult's kinematics?

What are the kinetic and kinematic metrics that should be extracted from the performance of specific tasks to characterize older adult's movement?

2. Methods

2.1 Data Sources

The literature search was wielded following PRISMA Extension for Scoping Reviews, PRISMA-ScR (Tricco et al., 2018). Search and identification of studies were made in three different electronic databases, namely PubMed, Web of Science, SCOPUS, using the following search terms combinations, ("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*") AND (guideline*) AND ("biomechanic*" OR "movement analysis" OR "movement assessment*" OR "movement evaluation*" OR "kinetic*" OR ”kinematic*" OR "task*" OR "gait" OR "sit-to-stand" OR "climbing stair*"). MeSH terms were used in PubMed and search algorithms were adapted to the other two databases, and specifications of the search are present in Supplementary material (Appendix XII).

2.2 Inclusion and Exclusion Criteria

Studies were included if they addressed guidelines to evaluate older adults' kinematics during the performance of different tasks task, namely gait, sit-to-stand, or climbing stairs. Studies approaching the guidelines about motor tasks, motion capture systems, and the kinematic and kinetic metrics that should be retrieved during older adults' movement analysis were also included. Studies were excluded if the population studied was institutionalized, included exclusively specific pathologies or conditions, or if the variables assessed were other than kinetic or kinematic. No limitation of date was applied to widen the identification of the types of available evidence in this field, and all studies until the search date (June 14th, 2021) were included. The Portuguese, English, French, and Spanish languages were considered for analysis.

2.3 Data Extraction, and Data Synthesis

Database search results were gathered, and duplicates removed, in the EndNoteTM (ClarivateTM), version 20, software and Rayyan web application©. Studies’ titles and abstracts were assessed by one reviewer also using Rayyan web application©. Data were retrieved from included studies using a standardized data extraction table previously defined by the authors, which included the information of authors, year and title for identification of the study, the population, task, motion capture systems, kinematic or kinetic metrics, and recommendations addressed by the study. As it was considered to include guidelines of older adults movement analysis a quantitative quality appraisal of the studies wasn't performed; instead, a qualitative analysis of the included studies was performed.

3. Results

The database search was yielded on June 14th, 2021, and a total of 8418 studies were identified.

By the analysis of title and abstract, the non-compliance with inclusion criteria led to the exclusion of 5678 studies, leaving 9 studies for full assessment of eligibility criteria. After full-text analysis, four studies were excluded, since one didn't appraise guidelines (Hars & Trombetti, 2013), other considered guidelines to assess kinematics of individuals with a specific pathology (Saggini et al., 2021), one didn't include kinematic assessment (Rikli & Jones, 1997), and one considered guidelines for falls assessment (Klenk et al., 2013). Accordingly, five studies were considered that included guidelines about older adults' movement analysis (Beauchet et al., 2017; Cullen et al., 2018; Kressig et al., 2006; Pasciuto et al., 2017; Ravi et al., 2020) (Figure 1).

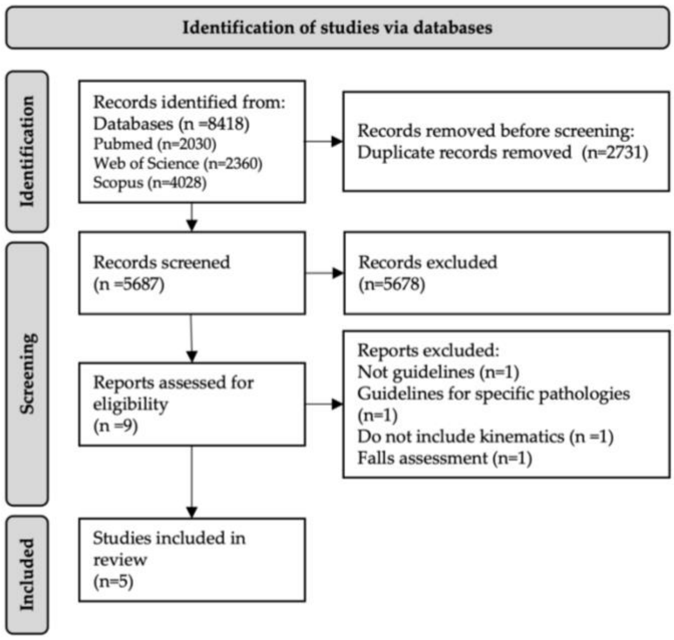

Figure 1: PRISMA flow diagram of studies retrieved from search, screening and selected for review.

Pasciuto et al., 2017 included young, older adults, and trans-femoral amputees, and Ravi et al., 2020 included young, older adults, and individuals with Parkinson Disease. The five included studies reported guidelines to assess older adults gait (Beauchet et al., 2017; Cullen et al., 2018; Kressig et al., 2006; Pasciuto et al., 2017; Ravi et al., 2020), but using different methodologies to draw the guidelines and focussing on different motion capture systems and kinematic variables. Both Beauchet, et al., 2017 and Kressig and Beauchet, 2006 focused on spatiotemporal gait parameters. Additionally, these authors focused exclusively older adults population as Cullen et al, 2018 directed to older adults with different cognitive impairments, Pasciuto, et al., 2017 included young, older adults, and trans-femoral amputees, and Ravi et al., 2020 included young, older adults, and individuals with Parkinson Disease.

Table 1: Characteristics of included studies comprising study identification, title, study design, population addressed or sample included in the study, and respective mean age (†NA not applicable; ‡NR non reported).

Author, year	**Title**	**Study design**	**Population/ Sample**	**Mean Age**
Beauchet et al., 2017(Beauchet et al., 2017)	Guidelines for assessment of gait and reference values for spatiotemporal gait parameters in older adults: The biomathics and canadian gait consortiums initiative	Three-step consensus of experts: • Expert group formation • Identification of items required for spatiotemporal gait analysis in older adults • Revision of guidelines Definition of quantitative reference values for spatiotemporal gait parameters based on the recorded footfalls	Older adults (n=954) 45,8% Female	72.8 ± 4.8
Cullen et al., 2018(Cullen et al., 2018)	Guidelines for Gait Assessments in the Canadian Consortium on Neurodegeneration in Aging (CCNA)	Consensus meeting of experts	Older Adults (with subjective cognitive impairments, mild cognitive impairment, vascular cognitive impairment, Alzheimer's disease, and frontotemporal dementia) (n=NA†) % Female NA	NA†
Kressig and Beauchet, 2006(Kressig et al., 2006)	Guidelines for clinical applications of spatio-temporal gait analysis in older adults	Consensus meeting of experts	Older adults (n=NA†) % Female NA†	NA†

Pasciuto et al., 2017(Pasciuto et al., 2017)	Overcoming the limitations of the Harmonic Ratio for the reliable assessment of gait symmetry	Analysis of three different datasets of individuals Proposition of guidelines	Elderly women (n=8) % Female NR‡	84±5 years
Ravi et al., 2020(Ravi et al., 2020)	Assessing the Temporal Organization of Walking Variability: A Systematic Review and Consensus Guidelines on Detrended Fluctuation Analysis	Systematic literature review Recommendations are derived from the qualitative analysis performed within the systematic review	Older adults (n=149) % Female NR‡	68.5±6.0 years

3.1 Studies design and aims summary

As described in Table 1, Beauchet, et al., 2017 and Kressig and Beauchet, 2006 formulated the guidelines resorting to the procedure of a consensus of experts. Kressig and Beauchet, 2006 organized a meeting of clinicians. The Canadian Consortium on Neurodegeneration in Aging (CCNA), also following a consensus meeting (Cullen et al., 2018), agreed on gait measurements that would test both mobility and cognition. Pasciuto et al., 2017 considered three different datasets of individuals characterized by a theoretical difference in gait symmetry, and defined guidelines to follow for reliability and comparability purposes. The study aimed to assess the influence of the number of harmonics and strides on the estimate of the Harmonic Ratio index. This is the "ratio between the sum of the amplitudes of the intrinsic harmonics and the sum of the amplitudes of the extrinsic harmonics of the acceleration components along each axis" (Pasciuto et al., 2017). To accomplish the goal established Pasciuto, et al., 2017 performed an observational study with eight young healthy adults (age:27±4 years); eight elderly women, with no neurological disorder who could ambulate independently (age: 84±5 years); and eight male trans-femoral amputees (age:41±9 years). Ravi et al., 2020 performed a systematic literature review to understand the thresholds in scaling exponent α for discriminating young compared to older adults, as well as between patients with Parkinson Disease and age-matched asymptomatic controls. The authors derived recommendations from the qualitative analysis performed in the systematic review.

3.2 Main objective A: guidelines

The guidelines established are summarized in the table 2. Beauchet et al., 2017, divided them into three categories, namely demographic characteristics, clinical characteristics, and gait characteristics. For each category, the authors described which parameters should be assessed and briefly reported considerations about the data collection environment. A division into categories was also adopted by Cullen, et al 2018, addressing the environmental conditions, recommending a clinical assessment consisting only in the gait observation, and describing the 8-meter walking testing path. CCNA proposes a gait and cognitive task assessment divided into three main walking conditions (usual gait velocity, dual-task gait at usual gait velocity, and fast gait).

Focusing only on spatiotemporal gait parameters Kressig and Beauchet, 2006 divided guidelines into environmental measure conditions and safety issues, aiming the reproducibility of the measurement, and measurement procedures, considering the instructions to participants and suggesting a minimum of three consecutive gait cycles for both left and right sides.

Pasciuto et al., 2017 defined guidelines to follow for reliability and comparability purposes on the assessment of gait symmetry resorting to Harmonic Ratio.

Finally, Ravi et al., 2020 described recommendations for practical usage of Detrended fluctuation analysis for understanding the fractal dynamics of human walking and divided them into the calculation, reporting, and interpretation parameter.

Table 2: Summary of guidelines proposed by included studies († DFA: Detrended fluctuation analysis).

Study ID	Guidelines
(Beauchet et al., 2017)	Demographic characteristics:Age, Sex, Ethnicity Clinical Characteristics: Anthropometric items [height (meters), weight (kilograms), body mass index (kilograms/meter^2)]; Medication and Information about history of falls and fear of Falling; Disorders that directly influence gait performance; Global cognitive functioning and Depressive and Anxiety symptoms Information on sensory and motor subsystems (muscle strength, lower-limb proprioception, vision); Use of walking aid Gait Characteristics: Subjective perception of gait difficulties: Gait during habitual walking (visual observation), Timed up and go test score and gait speed; Quiet, well-lit environment and participants wearing their footwear; Steady state walking (acceleration and deceleration phase of 1m each) usual self-selected walking speed

(Cullen et al., 2018)	Environmental Conditions: Quiet assessment area (closed room with no auditory or visual interference), with artificial light control; Participants wearing their own shoes [closed walking shoes (no slippers), heel height < 3 cm] and nonrestrictive clothes (same in baseline and follow-up); Safety-belt around the participant's waist and Electronic walkways edges should be attached to the floor Clinical Assessments: Gait observation Walking Testing Path: 8 meters (6-meter path, capturing at least 12 steps in steady-state walking) Gait and Cognitive Task Assessment: Usual gait velocity (walk at a comfortable and secure pace): 3 gait trials (12 steps minimum), walking in the same direction (participants with a gait velocity <0.6m/s, or with lower limb disability, allowed to complete one walk); Dual-task gait at usual gait velocity: 3 trials each with a cognitive task; Fast gait: Participants instructed to walk as fast and safely as they can Standardized Walking Instructions: Explain the various tasks to participants Assistive Devices: Participants wearing their glasses, hearing aids and assistive walking devices Prioritization: Instructions of tasks while dual-task testing will depend on the main research question
(Kressig et al., 2006)	Environmental Measure Conditions and Safety Issues Reproducible, quiet, well-lit environment; Participants with comfortable and non-restrictive clothing, in their own footwear, glasses and hearing aids Safety measures - safety-belt around the participant's waist Measurement Procedures: Steady-state gait at different gait speeds in randomized order, minimum of 3 consecutive gait cycles (left and right sides); Simple, clear, and standardized walking instructions to explain the various tasks to participants; Gait analysis simultaneously with cognitive tasks; Classify participants by frailty status and/or by living condition
(Pasciuto et al., 2017)	For reliability and comparability purposes: At least 20 harmonics ensure a greater stability of the index At least 20 strides lead to a more stable median index value; A verticalized system of reference enhances the comparability of the results ensuring a greater uniformity of starting conditions; Improved index proved to present a greater robustness and reliability with respect to the traditional Harmonic Ratio
(Ravi et al., 2020)	Calculation: Study constraints that my influence the dynamics of human walking; Calculate power and sample size estimation; Segment kinematics should be collected at 120Hertz and avoid filtering kinematic data where possible; Walking time series of at least 500 to 600 strides (straight-line walking); Window sizes of 16 to N/9 to calculate the slope of log F(n) vs. log n "(N" is the time series length and "n" is the window size); Use of a median filter for removal of outliers; Employ a second-order detrending procedure in the determination of DFA† scaling exponent α; To reduce the variability involved in estimating the scaling exponent α, derivation of a should occur from an evenly spaced DFA† plot; Calculate fit (R2) of exponent α Reporting: Summary of study information (methodological choices; population demographics; confounding factors) Interpretation: 1.0 signifies an optimal state of adaptability in motor performance, 0.5 suggests unconstrained variability and unstable motor performance; A scaling exponent a threshold of 0.86 (CI, 0.76–0.96) and 0.82 (CI, 0.72–0.92) practically discriminates movement performance between age- and Parkinson Disease related influences regarding the nature of long range correlations of stride interval

3.3 Main objective B, C and D: Motor task, Motion capture systems and Kinematic and Kinetic metrics

The included studies reported guidelines to assess the gait task (Table 3). Beauchet, et al, 2017 and Kressig and Beauchet, 2006 detailed guidelines for the evaluation of spatiotemporal parameters when collected by an electronic walkway with an integrated pressure-sensitive electronic surface, the GAITRite®. Kressig and Beauchet, 2006 also reported guidelines for spatiotemporal parameters reported by the GAITRite® but didn´t specify the variables assessed. Cullen, et al, 2018 recommend the use of electronic walkways indicating also the GAITRite® and adding the Zeno Walkway System®. CCNA group also highlighted spatiotemporal quantitative variables, isolating the gait velocity due to its association with deleterious health outcomes. Pasciuto, et al, 2017 propose standardized guidelines for the evaluation of symmetry of gait throughout the Harmonic Ratio index measured by accelerometers integrated into magneto-inertial measurement units. Ravi et al. 2020 presented guidelines about the stride interval dynamics expressed by the Detrended fluctuation analysis scaling exponent α, a measure that translates temporal organization of walking variability. As the data synthesis of the studies included in the systematic review, authors reported different motion capture systems used to assess the Detrended fluctuation analysis, as described in Table 3.

*Table 3: Tasks, systems, and kinematic metrics addressed in the included studies († M mean value, ‡CoV Coefficient of variation; *SR Sampling rate).*

Study ID	**Task**	**System**	**Kinematic metrics**
Beauchet et al., 2017(Beauchet et al., 2017)	Gait • Overground • usual self-selected walking speed	GAITRite® system • recording area of the gait mats from 4.6m to 7.9m	Spatiotemporal gait parameters: Walking speed [M† (cm/s)] Stride, Swing, and Stride time [M† (ms), CoV‡ (%)] Additional parameters: Stride length [M† (cm), CoV‡ (%)] Stance, Single support, Double support time [M† (ms), CoV‡ (%)] Stride velocity [M† (cm/s), CoV‡ (%)]

Cullen et al., 2018(Cullen et al., 2018)	Gait • Overground • Preferred or usual gait • Arithmetic dual-task • Category fluency dual-task • Fast gait	GAITRite® or Zeno Walkway System® • 6-meter electronic pathway • capture at least 12 steps in steady-state walking	<u>Gait Velocity</u> <u>Spatiotemporal Quantitative Gait Variables:</u> Cadence (steps/min), Stride and Double support time (milliseconds), Stride length and Step width (cm) <u>Gait Variability:</u> stride-to-stride variation in time/distance of the variables listed above <u>Dual-Task Gait Cost</u>: [(usual gait-dual-task gait)/usual gait]×100 <u>Dual-Task Cognitive Cost:</u> [(Single-task cognition-dual-task cognition)/Single-task cognition]×100
Kressig and Beauchet, 2006(Kressig et al., 2006)	Gait • Overground • Steady-state gait at different gait speeds, preferably in randomized order (slow, normal, fast)	GAITRite® system	Spatiotemporal gait parameters (non-specified)
Pasciuto et al., 2017(Pasciuto et al., 2017)	Gait • Overground • Self-selected speed	Accelerometers in magneto-inertial measurement units (MIMUs) (FreeSense, Sensorize s.r.l. Rome, Italy) • SR* of 100 Hz • 50m straight pathway for six min	Harmonic Ratio (HR)
Ravi et al., 2020(Ravi et al., 2020)	Gait • Overground • Treadmill	Footswitches • SR* 1,942; 100; 300 Hz Inertial measurement units • SR* 100; 128; 512 Hz Motion capture • SR* 100; 200 Hz iPod Touch • SR* 88-92 Hz	Stride interval dynamics expressed by Detrended fluctuation analysis scaling exponent α

4. Discussion

This scoping review presents the search and summary of guidelines concerning motor tasks performed, motion capture systems used, and kinetic or kinematic metrics evaluated in the assessment of the specific older adult's population kinematics.

Considering that the overall screening of the 8418 results of database search resulted in only five included studies, it is anticipated that there is a lack in the literature of guidelines specific for older adults movement assessment. It could be argued that there are standard biomechanical guidelines, as the defined and established by the International Society of Biomechanics (Biomechanics, 2020), or the Italian Society of Clinical Movement Analysis, SIAMOC (Benedetti et al., 2017), specific for the gait analysis. However, older adults experience a biological modification process (Frontera, 2017; Seidler et al., 2010) assuming a large set of particularities as well as other studied populations like post-stroke patients whose guidelines have been already settled (Mesquita, Fonseca, et al., 2019; Mesquita, Pinheiro, et al., 2019). Moreover, an international consortium of scientists with the aim of develop a clinically-valid digital mobility assessment system, uniformly applicable across conditions, has developed first steps towards standards for Parkinson (Gaßner, Sanders, et al., 2020; Viceconti et al., 2020), Multiple Sclerosis (Angelini et al., 2019) and Huntington disease's (Gaßner, Jensen, et al., 2020) patients. Thereby, it is reinforced the need to specify guidelines for the movement data collection and analysis of older adult's population as these scarce resources hamper researchers to implement reliable protocols and to compare or gather results from research.

Although this scoping review aimed to search for guidelines for different tasks, in all included studies, the gait was the task evaluated (Beauchet et al., 2017; Cullen et al., 2018; Kressig et al., 2006; Pasciuto et al., 2017; Ravi et al., 2020). The prioritization of the gait task may rely on its importance for human locomotion but also on the age-related decline and increased variability (Kobayashi et al., 2016; Osoba et al., 2019) which have been associated with increased risk of falls (Osoba et al., 2019) and increased risk of institutionalization and death (S Studenski et al., 2011; Verghese et al., 2006). However, the analysis of other functional tasks also revealed important information for older adult's movement analysis (Buckley et al., 2009; Kuo et al., 2010; Novak & Brouwer, 2011; Reid et al., 2010; Wang et al., 2003), and therefore a set core of guidelines should be gathered considering the particularities for the performance of stair ascend and descend, forward and lateral stepping, sit-to-stand or sit-to-walk.

Considering the exposed, for purposes of standardization and comparability of literature, it would be valuable to develop guidelines specific to motion capture with these instruments, considering the different most common imaging systems (APAS©, Vicon©, Qualisys®, and SIMI®) (Gordon et al., 2014).

Beauchet, et al,, 2017, Cullen, et al., 2018, and Kressig and Beauchet, 2006 focused on several spatiotemporal parameters, the symmetry of gait throughout the Harmonic Ratio index (Pasciuto et al., 2017), and the stride interval dynamics, which can be also included in the category of spatiotemporal parameters (Ravi et al., 2020). As different aspects of the spatiotemporal gait pattern can be relevant in clinical practice and research, and the choice of which aspect of the spatiotemporal gait pattern is relevant depends on the characteristics of the older persons (Lindemann, 2020), researchers should set guidelines for which spatiotemporal parameter to be evaluated, considering the older adult's characteristics and also the appropriate methods for its collection. Accordingly, Beauchet, et al, 2017 defined as the main variables to be measured the walking speed, the stride and swing time, and the stride width. The guidelines developed by Cullen, et al, 2018 recommends also the assessment of the cadence, the stride length, the step width, and the double support time, which are in accordance with the additional parameters enumerated by Beauchet, et al, 2017. The Cullen, et al, 2018 also point the assessment of gait variability using the previous variables stride-to-stride variation. Pasciuto, et al., 2017 and Ravi et al. 2020 defined guidelines for specific variables in the context of variability. Therefore, the different guidelines included in the review present complementary spatiotemporal parameters, reporting them as essential to characterize older adult's gait. Complementary, in the guidelines established by Beauchet, et al, 2017, Cullen, et al, 2018, and Kressig and Beauchet, 2006 considerations about how the instructions should be given to this population were described. This guidance assumes highly importance in older adults population as the ageing impairs cognitive function (Partridge et al., 2018). Current literature states that to improve the following of spoken multi-step instructions, older adults benefit from planning for action (using techniques as motor imagery) rather than perform the actual physical movement (Jaroslawska et al., 2021). Cognitive function was explored in addition to gait assessment by Kressig and Beauchet, 2006 and, in greater detail by Cullen, et al., 2018, which recommends the assessment of dual-task gait at usual gait velocity, extracting variables correlated with the measures of cognitive ability.

Beauchet, et al., 2017 and Kressig and Beauchet, 2006 also included directions to evaluate some clinical features such as the history of falls and the fear of falling, considering that the falls occurrence is a frequently used indicator in the classification of older adults' morbidity (Leach et al., 2018). These authors reinforced the clinical observation of gait, wherein Cullen, et al, 2018 recommend its classification. These three guidelines also included concordant conditions of data collection environment, such as the recommendation to collect data in a closed room, with no auditive or visual interference and controlled lighting. The adoption of these guidelines is of high importance since environmental conditions actively influence the subject behavior (Gordon et al., 2014). Nevertheless, a distinction between laboratory and clinical settings would be valuable. Additionally, authors recommend the use of the participant's own and comfortable shoes, and the adoption of safety measures such as safety belt use around the participant's waist. Pasciuto, et al., 2017 and Ravi et al., 2020 focused predominantly on the calculation processes to ensure maximal reproducibility and accuracy of the measures computed, and as stated by the authors, this can only be achieved following standard methodology (Ravi et al., 2020).

Study limitations

Despite the high agreement between the guidelines found, the title and abstract screening by one reviewer and the limited number of databases searched, represent limitations of this review. To overcome these limitations, the screening process was conducted using the Rayyan web application©, and was performed twice to ensure that no study with eligibility criteria was excluded. Nevertheless, its results are supported by the conclusions of included studies, which state that the included studies represent the first steps in the development of different guidelines (Beauchet et al., 2017; Cullen et al., 2018). Additionally, the authors underlined the importance of these guidelines, and future additions, to effectively analyse and compare studies addressing older adults' movement and enhance common knowledge (Beauchet et al., 2017; Ravi et al., 2020).

5. Conclusions

The present scoping review gathered existing guidelines specific for the assessment of older adults' movement analyses. The current guidelines focused on methodological aspects for the assessment of demographic, clinical, and gait characteristics, reliability and comparability purposes of gait symmetry assessment, and recommendations for the usage of Detrended fluctuation analysis for understanding the fractal dynamics of human walking. The guidelines considered the gait task, focusing mainly on spatiotemporal parameters, computed by different motion capture systems. Future research should explore tasks beyond gait relevant to older adults' daily activities, considering suitable motion capture systems and accuracy. Guidelines must address the multidimensional aging process, standardizing data collection, environmental conditions, computation, reporting, and interpretation of metrics to ensure comprehensive and reliable assessments.

Supplementary material: Supplementary material includes search strategy information (Appendix XIV).

Study IV - Kinematic and kinetic gait principal component domains in older adults with and without functional disability: a cross-sectional study

Submitted to a scientific journal

ABSTRACT

Background and Objective: Gait kinematic and kinetic changes have been identified in older adults, highlighting the need to explore the principal aged-related components and how these are associated to functional disability. This study aims to perform a factor analysis including gait kinematic and kinetic parameters in older adults to establish determinant gait domains and identify which differentiate those without and with disability.

Methods: Through a cross-sectional design older adults aged 60 or over (n=35 without and n=25 with disabilities), were analyzed during overground gait. A Principal Component Analysis (PCA) was used to determine principal components from gait parameters previously demonstrated to express age-related effects (spatiotemporal parameters, sagittal range of motion (ROM), sagittal ankle moment and power, ground reaction forces (GRF) peak and lower limb joints ROMs and positions at heel strike (HS) and toe-off (TO) in the frontal and transverse planes.

Results: P*ace* (step, stance, and swing time), *Variability* (step, stance, swing time, step velocity), *Propulsion (*sagittal peak ankle power, vertical GRF second peak, antero-posterior GRF peak), *Hip and knee control* (transverse hip angle at TO and HS, frontal knee angle at TO), *Transverse ankle control* (transverse ankle angle at TO and HS), *Asymmetry* (swing, step, stance*)*, *Sagittal ankle control* (ankle peak plantar-flexion, sagittal ankle angle at TO), *Frontal ankle control* (frontal ankle angle at HS and TO), *Frontal hip control* (frontal hip angle at TO and HS), and *Pre-swing control* (ankle peak dorsiflexion moment) domains explained 83,90% of total variance of older adults gait. *Pace* and *Frontal Hip Control* distinguished individuals with disabilities.

Conclusions: PCA identified ten gait domains in older adults. Pace and Frontal Hip Control distinguished disabilities, revealing cautious walking patterns and weaker hip abductor strength.

Keywords: Gait, Geriatrics, Biomechanics, Factor Analysis

1. Introduction

Dimensionality reduction methods, such as principal component analysis (PCA), have been proposed to group gait characteristics into distinct domains, offering a more comprehensive understanding of the key domains of gait in older adults (Hagoort et al., 2023; Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008). Different key domains have been proposed depending on the number of individual gait variables considered. Pace, rhythm, and variability were identified from eight individual gait variables (Verghese et al., 2008), phases of gait cycle and base of support were added to the previous one when 23 individual gait variables were considered (Hollman et al., 2011) and asymmetry and postural control domains parameters were added when adding these parameters and using step rather than stride characteristics (Lord et al., 2013). More recently, it has been demonstrated that despite variability, pace, stability, time and frequency, and complexity components characterize older adults gait, only the time and frequency domains have been demonstrated to be affected by age (Hagoort et al., 2023). Beyond these evolving results, it should be noted that the previous mentioned studies propose key gait components of older adults based on spaciotemporal parameters only. Evidence supports moderate standardized effects showing reductions in hip and ankle joint movements peak ankle moments, power generation, and ground reaction forces in older adults (Boyer et al., 2017; Pol et al., 2021). Accordingly, understanding how the inclusion of additional gait mechanics parameters like kinetics and angular kinematics influences factor distribution is essential.

Several metrics related to spatiotemporal gait parameters demonstrating aged-related effects have been linked to an increased risk of disability in this population (Abdul Jabbar et al., 2021; Artaud et al., 2015; Perera et al., 2016). Specifically, gait speed was demonstrated to be correlated with hand grip strength (Abdul Jabbar et al., 2021), can predict incident disability (Perera et al., 2016) and its accelerated decline in fast gait speed is also associated with disability, irrespective of baseline fast gait speed (Artaud et al., 2015). However, because this association was based on single spatiotemporal parameters comparisons, the comparative factor analysis of gait domains, including angular kinematics and kinetics, between older adults aging healthily and those with disabilities is also needed.

Building on these insights, this study aims to conduct a factor analysis including gait tridimensional angular kinematic and kinetic and spatiotemporal parameters in older adults. The goal is to identify key domains of older adults gait and identify those that can differentiate individuals with and without disability.

To develop this comprehensive model of gait, the present study will consider different gait parameters including: 1) spatiotemporal (step time and length, variability and asymmetry, stride length, variability and asymmetry, swing and stance time, variability and asymmetry and step velocity, variability and asymmetry (Lord et al., 2013)); 2) joint kinematics (lower limb joint range of motion (ROM) and positions at heel strike (HS) and toe-off (TO) in the frontal and transverse planes) and 3) kinematic and kinetic measures systematically reviewed (sagittal knee and ankle ROM, sagittal ankle angle at TO, peak hip extension and peak ankle plantar flexion, second peak of vertical ground reaction force (GRF 2nd peak), anteroposterior GRF propulsion peak, sagittal peak ankle power generation and peak ankle dorsiflexion moment (Boyer et al., 2017)). This consolidative approach aims to establish a robust model of gait performance in older adults.

2. Methods

2.1 Study design and context

This cross-sectional study is part of a broader research initiative registered in the ClinicalTrials.gov database (identifier: NCT05611723) and adheres to the guidelines set forth by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (Elm et al., 2008).

The research was undertaken at the Center for Rehabilitation Research, School of Health Polytechnic of Porto, between June 1, 2022, and March 31, 2023. The study was approved by the Institutional Ethics Committee on May 25, 2022 (Registration Number: CE0064C). Data collection was executed from June 1, 2022, to April 30, 2023. All participants received information about the study's purpose and methodology, and they completed an informed consent form.

2.2 Sample selection and characterization

A sample selection questionnaire was distributed to partner institutions of the research center. Participants meeting eligibility criteria and providing voluntary consent were contacted. A detailed questionnaire was administered to gather demographic information, health conditions, prescribed medications, history of falls in the past 12 months, results from the Mini Mental State Examination (MMSE), and the seven-item short version of International Physical Activity Questionnaire (IPAQ). This questionnaire included also indicators to assess disability (Moreira et al., 2022), particularly self-reported health (SRH), the Barthel Index of Activities of Daily Living, and the Lawton & Brody Instrumental Activities of Daily Living Scale. Disability was further assessed through handgrip strength and the One-Leg Standing Test (OLST). Older adults were characterized as having disability if met two or more disability indicators.

Anthropometric measurements were taken, with body mass (kg) assessed by bioimpedance analysis (Tanita Inner Scan BC-601) and height measured using a seca® 222 stadiometer (seca—Medical Scales and Measuring Systems®, Birmingham, UK), with 1 mm precision. Information on prescribed medications was collected, with polypharmacy defined as the use of five or more prescription medications (E. A. Lee et al., 2020). The MMSE (Folstein et al., 1975), was administered to evaluate cognitive function, covering temporal and spatial orientation, short-term memory, calculation, coordination, language, and visuospatial skills. Total MMSE scores range from 0 to 30, with scoring criteria adjusted for literacy levels: 22 for 0–2 years of literacy, 24 for 3–6 years, and 27 for 7 or more years (Morgado et al., 2009). Self-reported physical activity was assessed by the seven-item short version of IPAQ, considering moderate and vigorous physical activity (Craig et al., 2003).

Overall SRH was assessed through the question, "In general, how do you rate your health today?" with response options of "Very bad," "Bad," "Fair," "Good," and "Very Good." SRH was then dichotomized into "Good" (responses of "Good" or "Very Good") and "Poor" (responses of "Fair," "Bad," or "Very Bad") categories (Crimmins, 2004). The Barthel Index was used to evaluate participants' independence in ADL (Araújo et al., 2007; Mahoney & DW, 1965). The scoring system of 0 indicating complete dependency and 20 indicating functional independence was used as this scoring correct for a uneven impression of accuracy (Collin et al., 1988). Functional capacity was further assessed using the Lawton & Brody Scale (Lawton & Brody, 1969), which measures independence across seven instrumental activities of daily living (IADL), with total scores ranging from 7 to 23 (Araújo et al., 2008).

Handgrip strength was measured with a Jamar® Plus+ Digital dynamometer (Performance Health Supply, Cedarburg, WI, USA), with participants seated, shoulder adducted, elbow flexed at 90 degrees and unsupported, forearm in a neutral position, and wrist extended to 30 degrees, following guidelines by the American Society of Hand Therapists (Jansen et al., 2008). The OLST was conducted on the preferred leg, with eyes open, to measure balance in seconds (Furuna et al., 1998). Timing ceased when the participant lost balance (e.g., the flexed leg touched the ground), with a maximum duration of 60 seconds (Furuna et al., 1998).

2.3 Procedures

The kinematic and kinetic data were collected synchronously using the Qualisys Track Manager(R) (Qualisys AB®, Sweden) with eleven optoelectronic cameras (eight Oquos500, three MiqusM3), one Miqus video camera (Qualisys AB®, Sweden), and two force plates (FP4060-08/10, Bertec®), at a sampling frequency of 100 Hz (Richards, 2018). A marker setup adapted from the collaboration between Istituto Ortopedico Rizzoli and other authors (Cappozzo et al., 1995; Leardini et al., 2011; Leardini et al., 2007), augmented with the head segment (C-motion, 2017) and Rab Upper Extremity Model (Petuskey et al., 2007) was used for data acquisition.

To assess overground gait, participants were instructed to walk a 10-meter, straight-level path at a comfortable, self-selected pace. Sufficient practice trials were provided to ensure a natural gait pattern. Participants achieved correct foot placement with full-foot contact on a force plate during five successful overground trials (Tsuchida et al., 2022). The force plates were aligned in sequence to capture the central gait cycles, thus excluding gait initiation and termination phases, with each recording positioned at the walkway's midpoint (Svoboda et al., 2017).

2.4 Data processing

Data were processed using both Qualisys Track Manager (Qualisys AB®, Sweden) to verify and identify markers trajectories, as well as to interpolate path deviations and interruptions through the linear, polynomial, and relational calculations integrated within the software. Subsequently, the data were exported to Visual3D Professional™ (C-Motion, Inc,, EUA) in which the full-body biomechanical model was constructed in accordance with the recommended guidelines from C-Motion (Has-motion, 2024). To eliminate minor random digitization errors and certain soft-tissue artifacts a Butterworth low-pass filter with a cut-off frequency of 6.0 Hz was applied (Richards, 2018).

A gait cycle was defined as the interval between two consecutive heel strikes of the same foot. The HS was identified when the vertical component of the ground reaction force (GRF) reached 20 Newtons (N), while TO was defined as the point at which this force fell to 20 N or below (Zeni et al., 2008). Each cycle was time normalized to 101 points representing equal intervals ranging from 0% to 100%.

2.5 Gait parameters for PCA

To conduct the factor analysis on spatiotemporal parameters, the rationale proposed by Lord and colleagues (Lord et al., 2013) was adhered to, emphasizing the inclusion of an adequate number of gait characteristics to ensure that the model accurately reflects the underlying construct of gait, while minimizing parameter redundancy. Specifically, the study relied on step characteristics due to their heightened reliability, maintained original measurement units, and incorporated measures of step asymmetry. Furthermore, the analysis utilized standard deviation (SD) instead of the coefficient of variation, defined as mean/SD × 100, as it provides greater clarity for interpretation (Lord et al., 2013). The spatiotemporal measures were included in a preliminary model that replicated the work proposed by Lord and colleagues (Lord et al., 2013). This model included in the analysis step, swing, and stance time, all measured in seconds; step and stride length, measured in meters; and step velocity, computed in meters per second. Variability and asymmetry were computed for these measures, with the exception of asymmetry in step velocity (Lord et al., 2013).

A second primary PCA model focused on lower limb joint ROM and positions at HS and TO in frontal and transverse planes.

The comprehensive PCA model of gait included, in addition to the parameters with loadings above 0.7 on the previous two models, the angular kinematic and kinetic measures identified in the systematic review and metanalysis of gait mechanics in young and older adults (Boyer et al., 2017), that demonstrated a statistically significant standardized moderate to large effect of age on gait. Specifically, kinematic measures included sagittal knee and ankle ROM, sagittal ankle angle at TO, peak hip extension and peak ankle plantar flexion. Kinetic measures included the second peak of vertical GRF (GRF 2nd peak), anteroposterior GRF propulsion peak, sagittal peak ankle power generation and peak ankle dorsiflexion moment.

Measurements of lower limb joint angles (hip, knee, and ankle) were recorded in degrees and calculated using the Cardan sequence, which assumes that the x axis is in the medial-lateral direction (positive flexion and negative extension movements), the y axis is anterior-posterior (positive abduction and negative adduction movements), and the z axis is in the up-and-down or axial direction (positive longitudinal internal and negative external rotation) as recommended by the ISB for the lower limb (Richards, 2018; Wu et al., 2002).

The method of inverse dynamics was employed to integrate kinematic data and external GRF in order to derive joint moments and powers at the ankle joints (Dicharry, 2010). Joint moment was normalized to the subject mass. The joint power was computed by combining the joint moments (Nm/kg) and joint angular velocities (rad/s), with positive values for joint power showing power generation (related to concentric muscle activity) and negative values showing power absorption (related to eccentric muscle activity) (Richards, 2018), with all measures normalized to the subject mass. Definitions for all gait parameters included in factor analysis are presented in Supplementary Table 1 (Appendix XV).

2.6 Data analysis

The demographic and clinical characteristics of the participants were analyzed using means and standard deviations, along with frequency counts to describe variables such as sex, history of falls in the past 12 months, polypharmacy, and SRH status. The normality of the distribution was evaluated using the Kolmogorov-Smirnov and Shapiro-Wilk tests for groups of older adults both without and with disabilities, respectively. Between-group comparisons of demographic and clinical characteristics were conducted using either Mann-Whitney tests or independent sample t-tests, depending on the normality of the distribution. Chi-squared tests were employed to assess between-group associations concerning categorical variables, specifically sex, history of falls, and SRH status.

PCA was conducted on kinematic and kinetic parameters, primarily in Lord and colleagues model replication and in the model including lower limb frontal and transverse ROM and positions at HS and TO. A correlation matrix was used to ensure that each variable contributed equally to the analysis. The correlation matrix was constructed based on standardized values, with each variable divided by its standard deviation to normalize the data, resulting in a mean of 0 and a standard deviation of 1 for all variables.

Potential outliers in the data were manually examined to ensure they would not exert an undue influence on the PCA results. No exclusion of outliers was required in any of the PCA models performed. The suitability of the dataset for PCA was assessed using the Kaiser-Meyer-Olkin (KMO) as measure of sampling adequacy and Bartlett's Test of Sphericity, which evaluates the appropriateness of the data for reduction. A significant Bartlett's Test result ($p<0.05$) and KMO values exceeding 0.5 were used to determine the fitness of the data for PCA. Principal components (PCs) accounting for the majority of the variance were extracted based on eigenvalues greater than 1. To enhance the interpretability of the components, a Varimax rotation was applied. The resulting rotated component matrix was analyzed to identify clusters of variables that loaded onto the same components, with an emphasis on variables exhibiting high loadings (loading > 0.7, in accordance with Hair et al. (Hair et al., 1998) for each component. The same procedures were applied to the comprehensive model including the measures with loadings >0.7 of the Lord and colleagues (Lord et al., 2013) model replication, complementary PCA model on lower limb positions in frontal and transverse planes and the kinematic and kinetic measures with statistically significant standardized moderate and high effect of age on gait, by Boyer et al., 2017 (Boyer et al., 2017). The differences between older adults with and without disability indicators across each of the kPCs of the comprehensive gait principal component model were assessed using the non-parametric Mann-Whitney U test, with a significance level set at 0.05. All analyses were performed using IBM SPSS Statistics for Macintosh, Version 29.0.2.0.

Results

3.1 Sample characterization

Out of 147 older adults who completed the eligibility questionnaire, 62 individuals enrolled in the study (Figure 1). During the evaluation, two participants displayed symptoms that impaired their performance, resulting in a final sample of 60 participants included in the analysis.

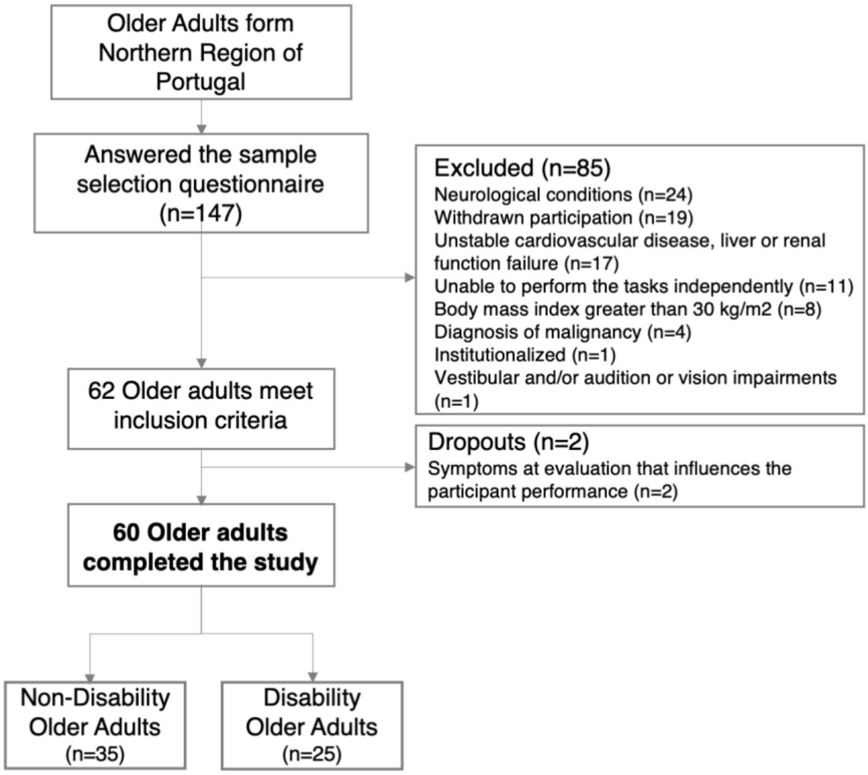

Figure 1: Flowchart of sample selection process

The demographic and clinical data showed no differences between older adults without and with disability, except for polypharmacy in which almost half of the group of older adults with disability toke 5 or more medicines per day (Table 1). The groups presented significant differences in all disability indicators.

Table 1: Demographic and clinical characterization of the sample. Data represented by the mean and standard deviation for ordinal variables, and frequencies for nominal variables. The p-value reflects the comparison between older adults without disability (ND) and older adults with disability (D) by (a) Mann-Whitney U test, (b) Chi-square test, (c) Independent samples t-test.

		ND (n=35)	**D** (n=25)	**P-value** (Test Value)
Demographic and clinical data				
Age (years)		66.34±5.60	68.60±6.77	0.147(534)(a)
Gender (n female; %)		19; 54.29	19; 76	0.085(2.961)(b)
BMI (kg/m^2)		25.22±3.08	26,02±2,66	0.298(-1.049)(c)
History of fall, previous 12 months (n fallers/%)		11 (31.4)	11 (44)	0.469(0.525)(b)
Polypharmacy (n polymedicated/%)		2 (5.71)	11 (44)	**<0.001**(12.595)(b)
Cognitive function (MMSE score)		28.94±1.31	28.68±1.49	0.495(394)(a)
Self-reported physical activity (IPAQ MET-min/week)		3186.46±2964.91	3519..66±2822.11	0.509 (393.5)(a)
Disability indicators				
Self-Reported Health	*poor*	8 (22.86)	21 (84)	**<0.001**(21.832)(b)
	good	27 (77.14)	4 (16)	
Hand grip strength (Kg)		36.59±39.86	25.07±7.54	**0.018**(279.5)(a)
One Leg Standing time (seconds)		38.83±20.93	18.19±20.72	**<0.001**(192.5)(a)
ADL independence (Barthel Index score)		19.97±0.17	19.76±0.44	**0.013**(345)(a)
IADL independence (Lawton & Brody score)		23±0.00	21.96±2.67	**0.002**(332.5)(a)

3.2 PCA primary models

The replication of Lord and Colleagues factor analysis (Lord et al., 2013), confirmed the adequacy of the current study's sample for dimensionality reduction (KMO=0.647 and Bartlett's Test of Sphericity p<0.001). The PCA model identified four components (explaining 79.3% of total variance), with the pace and rhythm gait spatiotemporal parameters loading onto the same component (see Supplementary Table 2 - (Appendix XV). The variability component defined by Lord et al., parameters such as step velocity variability, step length variability, and step width variability were included. Similarly, the present model included step velocity variability in the variability component but differed in including step time variability as well as swing and stance time variability. Step length, which Lord and colleagues associated with the *Pace* component, loaded onto the *Postural Control* component in this study. Specifically, the *Postural Control* component in the present model encompassed all spatiotemporal parameters related to length and width, including step length asymmetry, step length, step length variability, and step width. Accordingly, the parameters with loadings above 0.7, and thus included in the comprehensive model of gait were: step, stance, swing time, step velocity step time, stance time, step velocity and swing time variability, swing time, step time and stance time asymmetry.

The complementary factor analysis including lower limb frontal and transverse ROM and positions at HS and TO demonstrated suitable dataset characteristics for PCA (KMO=0.535 and Bartlett's Test of Sphericity $p<0,001$). Six components were retained, collectively explaining 79.19% of the data variance (see Supplementary Table 3 - (Appendix XV).

The first component primarily reflected ankle joint control in the transverse plane, capturing joint positions at TO and HS, as well as the transverse knee angle at TO, all with loadings exceeding 0.8. The second component included the transverse hip angle at HS and TO, along with the frontal knee angle at TO.

The third PC was defined by the frontal hip ROM, with a loading above 0.7, while the fourth PC was associated exclusively with the frontal ankle angle at HS and TO, both having loadings above 0.8. The fifth component comprised the frontal hip angle at TO and HS, whereas the sixth component was defined solely by the transverse hip ROM.

In summary, the parameters with loadings greater than 0.7 included the comprehensive model were the ankle joint control in the transverse plane (at TO and HS), as well as the transverse knee angle at TO, transverse hip angle at HS and TO, the frontal knee angle at TO, frontal hip ROM, frontal ankle angle at HS and TO, frontal hip angle at TO and HS, transverse hip ROM.

3.3 Comprehensive model of gait of older adults and differences between older adults with and without disability

The comprehensive model of older adults gait included 32 spatiotemporal, kinetic and kinematic variables (see Table 2). This comprehensive model retained ten PCs, named according to the representative set of parameters, explaining approximately 83,90% of total variance. The suitability of the dataset for PCA was ensured by a KMO=0,597, as well as sampling adequacy by the Bartlett's Test of Sphericity $p<0,001$. The pace, variability and asymmetry components were included in this model explaining 28.08%, 10.77% and 5.75% of total variance, respectively (Figure 2). The propulsion component (8.76%) gathered the kinetic measures of the ankle particularly the sagittal peak ankle power, the vertical GRF 2nd peak, and the AP GRF peak. The sagittal ankle ROM is also included in the propulsion component but with loading <0.7. The fourth PC included the transverse hip angle at TO and HS and the frontal knee angle at TO.

Additionally, the model grouped the variables of control of the ankle on transverse, sagittal and frontal plane, explaining 6.65%, 5.36% and 3.87% of total variance respectively. Finally, the component that explained less variance was the pre-swing control (3.50%) that loaded higher than 0.7 only the ankle peak dorsiflexion moment.

Table 2: Comprehensive model adapted from Lord and Colleagues, including measures of frontal and transverse lower limb joint angle complementary model and variables from systematic review by Boyer and Colleagues. Relevant item loadings (>0.7) in bold. Differences between older adults without and with disability assessed with the non-parametric Mann-Whitney U test, with a significance level set at 0.05.

Pace	Step time	**0,882**	0,284	-0,224	-0,052	-0,172	0,039	0,112	0,048	-0,095	-0,022
	Stance time	**0,862**	0,29	-0,28	-0,049	-0,182	0,024	0,074	0,057	-0,076	0,056
	Swing time	**0,81**	0,308	-0,086	-0,067	-0,13	0,111	0,178	0,031	-0,117	-0,208
	Step velocity	-0,698	-0,291	0,487	-0,083	0,147	0,125	-0,208	-0,06	-0,033	-0,122
Variability	Step time variability	0,362	**0,865**	-0,171	0,066	-0,169	0,008	0,078	0,067	-0,014	0,103
	Stance time variability	0,357	**0,853**	-0,169	0,076	-0,229	0,01	0,091	0,072	-0,015	0,063
	Swing time variability	0,39	**0,793**	-0,184	0,007	-0,069	0,037	-0,019	0,006	-0,012	0,127
	Step velocity variability	-0,02	**0,771**	-0,281	-0,026	0,03	-0,032	0,209	0,153	0,142	-0,116
Propulsion	Sagittal peak Ankle power	-0,179	-0,247	**0,829**	0,044	0,162	0,011	-0,053	0,05	0,003	0,075
	Vertical GRF 2nd peak	-0,303	-0,148	**0,749**	0,025	-0,023	-0,122	-0,074	-0,019	-0,123	-0,21
	AP GRF peak	-0,402	-0,29	**0,714**	-0,031	0,214	0,007	-0,066	-0,015	0,065	0,04
	Sagittal Ankle ROM	0,2	-0,044	0,59	0,202	0,343	0,07	-0,374	0,121	0,07	0,354
Hip and knee control	Transverse Hip angle at TO	-0,056	0,086	0,068	**0,903**	0,154	-0,008	-0,103	0,108	0,064	0,018
	Transverse Hip angle at HS	-0,104	-0,017	0,164	**0,845**	-0,015	-0,117	-0,085	0,031	0,171	-0,019
	Frontal Knee angle at TO	0,018	0,027	-0,23	**0,801**	-0,058	0,048	-0,055	-0,002	-0,265	0,078
	Sagittal Knee ROM	-0,161	-0,283	0,402	-0,481	0,365	-0,016	-0,117	-0,021	-0,151	0,055
Transverse ankle control	Transverse Ankle angle at TO	-0,173	-0,136	0,187	0,011	**0,871**	0,073	-0,048	-0,158	-0,074	0,015
	Transverse Ankle angle at HS	-0,136	-0,124	0,059	-0,136	**0,867**	-0,025	0,002	-0,262	-0,209	-0,005
	Transverse Knee angle at TO	0,231	0,112	-0,131	-0,477	-0,676	-0,004	0,071	0,025	-0,149	-0,136
Asymmetry	Swing time asymmetry	0,092	-0,135	-0,016	0	0,126	**0,878**	0,262	0,028	0,012	0,029

	Step time asymmetry	-0,151	0	-0,063	-0,138	0,057	**0,873**	-0,04	-0,058	-0,18	0,053
	Stance time asymmetry	0,069	0,39	0,064	0,127	-0,255	**0,704**	0,183	-0,029	0,039	-0,02
	Transverse Hip ROM	0,419	-0,064	0,004	-0,064	0,033	0,488	-0,137	0,038	-0,021	-0,07
Sagittal ankle control	Ankle peak plantar flexion	0,125	0,1	-0,181	-0,171	-0,082	0,11	**0,918**	0,07	-0,063	0,041
	Sagittal Ankle angle at TO	0,184	0,167	-0,072	-0,071	-0,013	0,134	**0,895**	0,112	-0,041	0,185
Frontal ankle control	Frontal ankle angle at HS	0,011	0,058	0,112	-0,013	-0,142	0,003	0,006	**0,951**	-0,102	0,034
	Frontal ankle angle at TO	0,122	0,147	-0,1	0,134	-0,224	-0,034	0,171	**0,895**	0,093	-0,036
Frontal hip control	Frontal Hip angle at TO	-0,028	0,117	-0,064	0,118	0,014	-0,037	-0,043	-0,054	**0,892**	-0,157
	Frontal Hip angle at HS	-0,193	-0,071	0,007	-0,117	-0,252	-0,131	-0,07	0,039	**0,792**	0,241
Pre-swing control	Ankle peak dorsiflexion moment	-0,066	-0,162	0,035	-0,164	-0,12	0,04	-0,306	-0,001	0,031	**-0,733**
	Frontal Hip ROM	-0,306	-0,196	0,466	-0,152	-0,15	0,055	-0,119	-0,108	-0,034	0,569
	Hip peak extension	-0,228	0,168	-0,284	-0,455	0,079	0,146	0,051	0,153	0,236	0,47
	p-value	**0.005***	0.725	0.297	0.816	0.702	0.770	0.946	0.534	**0.004***	0.946

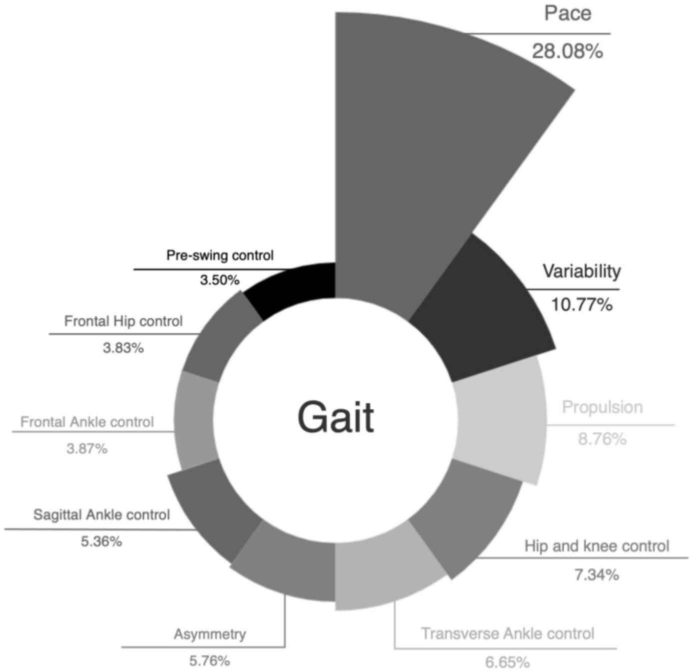

Figure 2: Total variance explained by the principal components of the comprehensive model of older adults gait.

Differences were identified between the PC scores of older adults without and with disability in the *Pace* and *Frontal Hip control* components (see Table 2). The mean values of gait parameters included in *Pace* component (swing, stance and step time) are illustrated in Figure 3A, highlighting significant group differences in stance time. Figure 3B depicts the frontal hip angle throughout the gait cycle, showing that while the overall behavior of older adults with disability is similar to their counterparts without disability, the former exhibit a more global adduction hip position and reduced ROM. These differences, when represented by the standard deviations of the disability group relative to their non-disabled counterparts, underscore the significance of additional measures, such as step time variability, transverse ankle angle at heel strike (HS), and stance time variability (Figure 3C).

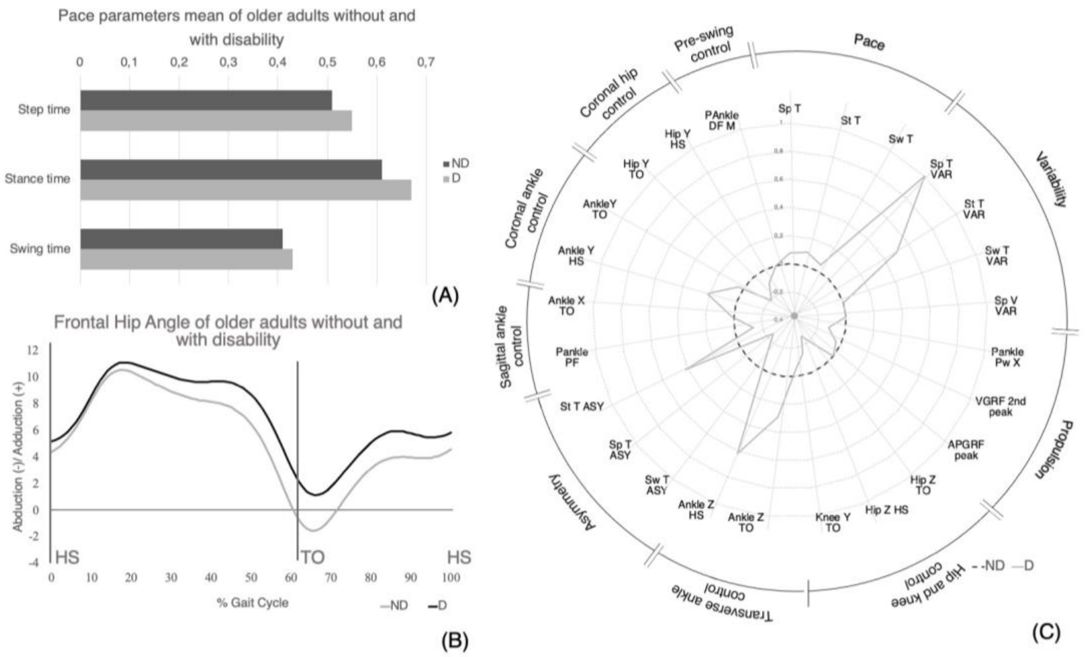

Figure 3: Plots of parameters included in principal components with significant differences in older adults without and with disability. (A) Pace parameters (step, stance and swing time) means for older adults without (ND and with (D) disability; (B) Frontal hip angle measured in degrees along the gait cycle of older adults without (ND and with (D) disability; (C) Standard deviations of the disability group (D) relative to their non-disabled counterparts (ND) for each parameter with loading >0.7 of the comprehensive model of older adults gait. Legend: *Sp T- Step time; St T- Stance time; Sw T- Swing time; Sp T VAR - Step time variability; St T VAR - Stance time variability; Sw T VAR - Swing time variability; Sp T VAR - Step velocity variability; Pankle PW X- Sagittal peak Ankle power; VGRFv2nd peak - Vertical GRF 2nd peak; APGRF peak - AP GRF peak; Hip Z TO/HS - Transverse Hip angle at TO; Knee Y TO - Frontal Knee angle at TO; Ankle Z TO/HS - Transverse Ankle angle at TO/HS; Sw T ASY - Swing time asymmetry; Sp T ASY - Step time asymmetry; St T ASY - Stance time asymmetry; Pankle PF - Ankle peak plantar flexion; Ankle X TO - Sagittal Ankle angle at TO; Ankle Y HS/TO - Frontal ankle angle at HS/TO; Hip Y TO/HS - Frontal Hip angle at TO/HS; PAnkle DF M - Ankle peak dorsiflexion moment*

3. Discussion

This study used PCA to identify specific domains of gait in older adults, encompassing angular kinematic, kinetic and spatiotemporal parameters. Additionally, it aimed to distinguish these domains between older adults with and without disabilities.

The rationale for this study builds on previous research that applied factor analysis to identify gait domains in older adults (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008). However, earlier studies were limited to spatiotemporal parameters, generally identifying three to five distinct gait domains (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008). More recently, Hagoort and colleagues advanced this approach by analyzing 27 gait measures, incorporating not only spatiotemporal parameters but also metrics that reflect the dynamic aspects of walking on a sample of healthy young and older adults (Hagoort et al., 2023).

In the present study, angular kinematic and kinetic measures of gait mechanics were included to provide a comprehensive understanding of older adults' performance and to examine how disability development in later life impacts this performance. The initial step involved replicating the model proposed by Lord and colleagues, which identified four components. However, the component comprising stride width, step length, and its asymmetry and variability had loadings below 0.7, leading to its exclusion from the comprehensive model of this study. The lower loadings of length-related measures may be attributed to the greater representativeness of stride length, compared to step length, in capturing age-related changes. Indeed, factor analyses using stride length measures have shown higher loadings for these parameters (Hagoort et al., 2023; Verghese et al., 2008). Similarly, the low loading of width-related measures aligns with previous research indicating that these parameters remain relatively stable across aging (Herssens et al., 2018).

Additionally, gait spatiotemporal parameters related to pace and rhythm loaded onto the same component. As emphasized by Lord and colleagues, gait characteristics do not always load onto identical domains (Lord et al., 2013). This inconsistency was observed in the other three components. For instance, all spatiotemporal parameters related to length and width were grouped within the postural control domain. This may reflect the strong interrelationship among spatiotemporal parameters and suggests that these measures alone offer a reductive perspective on gait performance (Hollman et al., 2011;

Lord et al., 2013). To address this limitation, angular kinematic and kinetic parameters with statistically significant standardized moderate to high age effects, as identified by Boyer et al., 2017, were included. However, these parameters predominantly focus on the sagittal plane (Boyer et al., 2017). Studies on gait analysis in older adults often prioritize sagittal plane parameters due to their clinical relevance, ease of measurement, and lower error rates compared to measurements in the frontal or transverse planes (Gordon et al., 2014; Stenum et al., 2024). While the sagittal plane provides critical insights into walking dynamics and the diagnosis of mobility impairments, there is growing recognition that multi-plane analysis is essential for a more comprehensive understanding of age-related changes in gait (Boyer et al., 2017; Gordon et al., 2014). Consequently, the second step involved analyzing the loading of joint positions in the frontal and transverse planes.

Therefore, the comprehensive model incorporated 32 variables, which were grouped into ten distinct domains. Among these, the domain that accounted for the largest proportion of variance was *Pace*, encompassing step, stance and swing time, as well as step velocity but with loading lower than 0.7. These findings align with previous factor analyses (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008), where pace and rhythm components consistently explained a substantial portion of the variance. This predominance may be attributed to the cautious gait behavior commonly observed in older adults, as identified in prior research (Herssens et al., 2018), but also to the impact of angular kinematic and kinetic adaptations of these variables (de Campos et al., 2022).

The second component identified was *Variability*, which included all parameters used to characterize gait variability such as step, stance and swing time variability and step velocity variability. The consistency of this domain can be attributed to the initial step of excluding parameters with non-representative loadings. The significance of these measures is crucial, as gait variability metrics have the potential to detect changes in the motor control system capacity to respond environmental and task constraints (Stergiou & Decker, 2011), even when the subsystems contributing to gait variability exhibit only subtle changes (Hausdorff et al., 2001). Moreover, the stance time variability presents as an independent predictor of future mobility disability (Brach et al., 2012).

The kinetic measures associated with the push-off phase of the gait, specifically, sagittal peak ankle power, the second peak of vertical ground GRF, and the anterior-posterior GRF peak, were grouped into a single component labeled *Propulsion*. This novel component aligns with and reinforces previous findings in the literature regarding the decline in forward propulsion observed in older adults, particularly the reduction in ankle push-off power (Sloot et al., 2021). While this reduction is typically reported in individuals aged 70 years or older (Sloot et al., 2021), the present study includes older adults aged 60 and above, with this component accounting for 8.76% of the total variance, suggesting that this changes may commence earlier. The literature attributes these declines to the functional consequences of sarcopenia and plantar flexor muscle weakness, as well as the underutilization of available muscular capacity (Franz, 2016). These age-related declines, combined with reduced flexibility, are reflected also in the *Sagittal ankle control* component, which includes the ankle peak plantar flexion and the sagittal ankle angle at TO (Pol et al., 2021).

The importance of the control in the transverse plane is elucidated through the *Hip and knee control* and *Transverse ankle control* domains. These components encompass the transverse hip and ankle joint angles at HS and TO gait events, parameters that have been minimally explored in the existing literature (Pol et al., 2021). However, the present results suggest that these aspects play a crucial role in the gait biomechanics of older adults, offering valuable insights into their functional mobility and potential gait adaptations.

In line with this, the joint behavior of older adults in the frontal plane was characterized by the *Frontal ankle control* and *Frontal hip control* domains. The pattern of elevation and depression of the iliac crests reflects the frontal plane hip motion, potentially indicating hip abductor weakness in older adults (Gordon et al., 2014). The gluteal muscles of the hip are particularly susceptible to adipose infiltration and reduced muscle fiber quality (Lanza et al., 2022), which may explain the prominence of this component in describing the gait characteristics of older adults. Notably, the *Frontal hip control* PC scores revealed significant differences between older adults with and without disability. Consistent with these findings, maximum voluntary isometric strength and rate of force generation of the hip abductors have been shown to possess good diagnostic accuracy in distinguishing between older fallers and non-fallers (Gafner et al., 2020). More importantly, hip abduction strength has been identified as a predictor of disability (Coyle et al., 2021). These physiological changes may be exacerbated in older adults with disability, who exhibit a more adduction hip position and reduced ROM throughout the gait cycle compared to their non-disabled counterparts.

Similarly, the *Pace* domain, which encompasses step, stance, and swing time, also demonstrated differences between older adults with and without disabilities. Older adults with disability exhibited increased durations of these parameters, aligning with evidence that identifies gait speed as a strong indicator of disability and other adverse outcomes (Abe et al., 2019; Cesari et al., 2009). Among these parameters, the step stance time showed the greatest disparity between groups, suggesting that older adults with disabilities adopt a strategy of prolonging the support phase of each limb during gait. This strategy is further highlighted by the variability of this parameter, as represented by the standard deviations of the disability group relative to their non-disabled counterparts. Indeed, literature underscores the importance of step stance time variability, identifying it as an independent predictor of mobility disability and a risk factor for future disability (Brach et al., 2012).

Additionally, differences in standard deviations emphasized the variability of step time and the transverse ankle angle at HS, further supporting the critical role of step time variability parameter in assessing mobility and predicting disability in older adults (Asai et al., 2019), and the need to further explore the transverse ankle kinematics (Pol et al., 2021).

The results of this study should be interpreted in light of its limitations, particularly the sample size. Nonetheless, measures of sampling adequacy and the appropriateness of the data for dimensionality reduction were rigorously ensured for all models employed. In contrast, prior studies often do not report on sample adequacy or data suitability for reduction (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008), an issue highlighted both in this scope as in related fields (Rojas-Valverde et al., 2020). Furthermore, the sample size in this study is larger than that of many biomechanical studies, which frequently involve small cohorts (Boyer et al., 2017). The retaining loadings were appropriately aligned with the sample size (Hair et al., 1998), addressing a common methodological shortcoming in previous studies, where loadings >0.5 were retained even with insufficient sample sizes (Hagoort et al., 2023).

Future studies should aim to replicate this model using larger sample sizes, which could enhance the robustness and precision of the model while enabling the integration of additional variables. For instance, although this study focused on kinetic measures identified through a systematic review, considering the integration of frontal and transverse plane kinetics could further deepen our understanding of gait in older adults. These measures, traditionally examined in contexts such as stepping (Hurt & Grabiner, 2015) or stair negotiation (Novak & Brouwer, 2011), are increasingly recognized as critical parameters of gait (Tillman et al., 2024). This approach would allow for a more comprehensive understanding of the underlying mechanisms and contribute to the generalizability of the findings. Given the consistency of the *Variability* component for the spatiotemporal parameters, including measures of joint kinematics and kinetic variability observed to vary with age (Kowalski et al., 2022), could provide valuable insights into the motor system's ability to adapt to diverse environmental and task constraints and consequently the capacity for adaptation (Stergiou & Decker, 2011).

4. Conclusion

Older adults angular kinematic, kinetic and spatiotemporal parameters gait performance of older adults can be characterized into ten domains, particularly *Pace*, *Variability*, *Propulsion*, *Hip and knee control*, *Transverse ankle control*, *Asymmetry*, *Sagittal ankle control*, *Frontal ankle control*, *Frontal hip control*, and *Pre-swing control*. The *Pace* and *Frontal hip control* domains differentiate individuals with and without disability, suggesting that older adults with disability exhibit more cautious gait behaviors and greater weakness in abductor musculature compared to their non-disabled counterparts.

Prospective research should consider replicating this model with larger sample sizes to strengthen its validity, refine its precision and integrate additional variables to potentially offer deeper insights into the multifaceted nature of gait biomechanics and disability in older adults.

Author contributions

CRediT authorship contribution statement

Juliana Moreira: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Validation; Visualization; Writing - original draft, review & editing.

Bruno Cunha: Formal analysis, Writing- review, Validation.

José Félix: Validation, Investigation, Data curation, Writing – original draft, review.
Rubim Santos – Writing - review, Validation, Supervision, Project administration.
Andreia S.P. Sousa: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Validation, Supervision; Validation; Visualization; Writing - review & editing.

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Data availability statement

The data-set generated and/or analyzed during the current study is not publicly available due to confidentiality of the data.

Declaration of conflicting interests

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics statement

The study adhered rigorously to the principles outlined in the Declaration of Helsinki. All participants received information about the study's purpose and methodology, and they completed an informed consent form. The study was submitted to the ESS, Polytechnic of Porto Institutional Ethics Committee on April 27, 2022, and obtained authorization on May 25, 2022 (Approval No CE0064C).

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Study V - Principal Component Analysis of Stair Negotiation and Floor Transition Kinematics in Older Adults with and without Functional Disability: Cross-sectional Study

Submitted to a scientific journal

ABSTRACT

Background: Stair negotiation, a complex motor task, is significantly affected by aging, yet the impact of disability on these changes remains underexplored.

Objective: To evaluate the lower limb joint positions, velocities and the center of mass (CoM) displacement and velocity during stair negotiation and transitions with floor in older adults with and without functional disability.

Methods: Community-dwelling individuals aged 60 and older participated in the study. Lower limb tridimensional joint positions and velocities during the instances of foot contact with step or foot leaving the step, and foot contact with floor or foot leaving the floor, the joint range of motion (ROM), angular velocity range (ΔVelocity) and the CoM displacement and ΔVelocity were assessed during stair ascend and descend and transitions floor-to-stair (F-S) and stair-to-floor (S-F) through an optoelectronic system. Principal component analysis assessed different group of variables to compute principal component models (PCMs). PCMI included position and velocity at the instant of step contact and PCMII for the instant of step leaving. The PCM III included range variables during stair negotiation and PCM IV CoM variables also during stairs negotiation. PCM V assessed the instant of floor contact and PCM VI the instant of leaving the floor. PCM VII included ranges during F-S and S-F and PCM VIII the CoM variables during transitions. Principal components (PCs) with eigenvalues above one were extracted, and variables loading above 0.7 were retained. The older adults sample was classified with or without disability based on limitations in at least two of the following indicators: handgrip strength, basic and instrumental activities of daily living, balance, and self-reported health and PCs group differences were assessed using the Mann-Whitney U test.

Results: PCA of 240 kinematic variables led to the selection of forty one kinematic parameters (loadings >0.7) retained in the PCMs, primarily associated with angular velocities of the hip and knee in the sagittal plane. CoM displacement and ΔVelocity PCMs IV and VIII retained sagittal plane parameters for both stair ascend and descend, as transverse plane on floor transition cycles. Twelve PCs significant differenced older adults with disability (n=25) and without disability (n=35).

Conclusions: Changes in sagittal plane hip and knee angular velocity and mediolateral and vertical CoM displacement and velocity, were identified in older adults with disability during stair negotiation and transitions. These insights carry implications for the development of targeted interventions aimed at supporting the stability and mobility of older adults, especially those with functional disability.

Trial Registration: ClinicalTrials.gov NCT05611723.

Keywords: Disability; Biomechanics; Stair negotiation; Gerontology; Kinematics; Factor Analysis

1. Introduction

Disability, as described by the International Classification of Functioning, Disability, and Health (ICF), embraces the impairments, activity limitations, and participation restrictions (WHO, 2001). It is a condition that requires assistance to overcome reliance or difficulty with everyday tasks and independent living (Fried et al., 2004). Aging is associated with systemic changes in the body, including deficits in cardiorespiratory function, slowness, strength loss, reduced flexibility, and weight loss, resulting in a decreased ability to perform daily activities (Khan et al., 2017; Partridge et al., 2018). These alterations increase the risk of mobility limitations (Khan et al., 2017) and physical disability (Fried et al., 2004) in older adults, making it crucial to reduce the length of handicap time and increase the well-being and independent time (Vos et al., 2020). Research and development investment are fundamental for effective intervention strategies, especially in the rapidly aging global population, requiring policymakers to anticipate these changes (Vos et al., 2020). Accordingly, to delay disability or prevent its occurrence, multidimensional assessment needs to be performed (Han et al., 2022). One hallmark of disability and functional decline in older adults is related to impairments in stairs negotiation (Tiedemann et al., 2007). These tasks are associated with a high risk of mortality and serious injuries (Jacobs, 2016), with estimates that twenty percent of falls occur on stairs (Ackermans et al., 2019), making them ten times more dangerous than walking (Kováčiková et al., 2021). The fact that this is one of the most hazardous daily activities is justified by its motor complexity, that by requiring precise coordination of joint movements, muscle forces, and balance control, poses a significant challenge for older adults (Williamson & Fried, 1996), particularly those with functional disability (Startzell et al., 2000).

The association between aging and biomechanical performance during stair negotiation has been reported in previous studies (Ackermans et al., 2019; Di Giulio et al., 2020; Kováčiková et al., 2021; Novak & Brouwer, 2011; Reid et al., 2010). Specifically, older adults seem to present slower cadence and higher variability of the hip joint angle curves in sagittal plane for ascent and descent stairs (Novak & Brouwer, 2011; Novak et al., 2011): Older adults also present higher maximum dorsiflexion angle(Reeves et al., 2008) and increased time to stair descent stairs, which was considered a functional decline predictor (Oh-Park, Wang, et al., 2011). A reduction of peak downwards and upwards center of mass (CoM) acceleration during the descent and landing phases respectively (Buckley et al., 2013) was also identified in older adults performance.

While age-related biomechanical adaptations in stair negotiation are well-documented, the extent to which these are associated to disability, as opposing to healthy aging, remains underexplored. Moreover, stair negotiation assessment should also encompass the sequences of walking to ascent stairs and descending stairs to walk, to represent the complete range of this daily activity. Therefore, it is important to evaluate not only stair use (stair ascent and descent) but also floor transitions (floor-to-stair (F-S) and stair-to-floor (S-F)). During stair use and transitions, beyond the range of kinematic parameters during full cycles of stair ascent and descent as well as F-S and S-F transitions, the assessment of key events could bring relevant data since at these transitional moments, older adults demonstrated more impairments in margin of stability (Bosse et al., 2012), lower downwards CoM velocity (Buckley et al., 2013), and lower peak moments during stair ascent and descent (Reeves et al., 2008). These changes lead to compensatory strategies prioritizing stability over range of motion, particularly when making or leaving contact with the step (Reeves et al., 2008). Addressing this research gap can provide valuable insights into the biomechanical contributors to stair negotiation impairments. Furthermore, this can inform the development of targeted interventions to improve stair performance, reduce fall risk, and enhance functional independence in older populations. Following this rationale, this study examines the kinematic differences in lower limb joint position and velocity at the instant of contact and leaving the step, the joint range of motion (ROM), the variation of angular velocity (ΔVelocity), and CoM displacement and velocity variation during stair ascent and descent cycles in older adults with and without disabilities. Additionally, it investigates the same kinematic variables at contact and leaving the floor moments, and transitions F-S and S-F cycles.

2. Methods

Study Design

A cross-sectional study following the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (Elm et al., 2008) guideline, was designed and implemented as part of an observational registered study in the ClinicalTrials.gov database (register identifier: NCT05611723). Between June 1st, 2022, and March 31st, 2023, a sample selection questionnaire was distributed to the partners of Center for Rehabilitation Research of the School of Health Polytechnic of Porto, where the study took place. The data collection continued until April 30th, 2023.

Participants

Individuals were enrolled in the present study if they were aged above 60 years old, community residents of the northern region of Portugal, and independently capable of completing the tasks (walking, sit and stand from a chair, and ascent and descent stairs). The following conditions precluded volunteers from participating in the study: institutionalization; had an established diagnosis of malignancy or terminal diseases with an anticipated survival of less than 1 year; had stroke history, cerebral hemorrhage, head trauma, or Parkinson's disease; had cognitive impairment, specifically Mini Mental State Examination (Portuguese version) score of 22 for 0 to 2 years of literacy, 24 for 3 to 6 years of literacy and 27 for more than 6 years of literacy (Morgado et al., 2009); had rheumatic pathologies that interfere with the tasks performance; had diabetic foot, lower limb fracture in the past 6 weeks, or other related conditions; had unstable cardiovascular disease, liver or renal function failure; had a body mass index greater than 30 kg/m^2; had uncorrected vestibular and/or audition and/or vision impairments that could influence the performance of tasks; or had symptoms at the time of evaluation that could influence task performance.

Procedures and Instruments

Sample selection and characterization

A questionnaire was used to characterize the participants regarding demographic data, health conditions, and history of falls in the past 12 months. Additionally, participants were characterized regarding anthropometric parameters (height, weight, body mass index), cognitive function (Mini-Mental State Examination), self-reported medication intake and self-reported physical activity (International Physical Activity Questionnaire: Short Form [IPAQ-SF] - Portuguese version).

Anthropometric parameters, specifically body mass (kg), were obtained by bioimpedance assessment (Tanita Inner Scan BC-601) , with a precision of 0.1 kg. Height was measured using seca® 222 stadiometer (seca—Medical Scales and Measuring Systems®, Birmingham, UK), with a 1 mm scale. The Mini Mental State Examination (MMSE) (Folstein et al., 1975) was applied to assess the cognitive function of the participants. The total score ranges from 0 to 30, with a score of 22 for literacy from 0 to 2 years, 24 for literacy from 3 to 6 years, and 27 for literacy of 7 years or more (Morgado et al., 2009). Medication intake was self-reported, and polypharmacy was defined as taking five or more prescription drugs (E. A. Lee et al., 2020). Self-reported physical activity was assessed by the seven-item short version of IPAQ (Craig et al., 2003).

Disability indicators characterization and assessment

Participants were divided into two groups: older adults without disabilities and those with two or more disability indicators of the previously identified in the literature(Moreira et al., 2022) namely: the handgrip strength (hand-held dynamometer), balance (single leg balance test time), overall self-reported health status (Self-reported question), basic activities of daily living (ADL) (Barthel Index) and instrumental ADL (IADL) (Lawton and Brody).

The handgrip strength was measured using a handheld dynamometer Jamar® Plus+ Digital (Performance Health Supply, Cedarburg, WI, USA). For the assessment participants were seated with the shoulder adducted, the elbow flexed at 90 degrees and unsupported, the forearm neutral, and the wrist at 30 degrees of extension, as advised by the American Society of Hand Therapists (Jansen et al., 2008). The total time spent standing (OLST) was measured in seconds using the participants' favored leg and with eyes open. The test was completed when the participants could not maintain the position or reached the maximum duration of 60 seconds. This time was used to determine when the individual became imbalanced (e.g., flexed leg contacting the ground) (Furuna et al., 1998).

By responding to the query "In general, how do you rate your health today? ", the overall self-reported health status (SRH) was evaluated as (Very bad, Bad, Fair, Good, Very Good". Good SRH (defined as "very good" or "good") and poor SRH (defined as "fair," "bad," or "very bad") were dichotomized (Crimmins, 2004). The participant's level of independence in the basic activities of daily living (ADL) was assessed using the Barthel Index (Mahoney & DW, 1965). The scoring system ranging from 0 (complete dependency) to 20 (functional independence), was used as this scoring correct for an uneven impression of accuracy (Collin et al., 1988). The internal consistency of the instrument is high, with a Cronbach's alpha of 0.94, and it has excellent reliability with a kappa coefficient of 0.79–0.88 and a weighted kappa coefficient of 0.87–0.9 (Araújo et al., 2007). The Lawton & Brody Instrumental Activities of Daily Living Scale (Lawton & Brody, 1969) was used to assess the functional capacity of older adults. It assesses seven instrumental activities, and the final score ranges from 7 to 23, corresponding to the maximum score of total independence. This instrument has high validity and reliability and a Cronbach's alpha of 0.91(Araújo et al., 2008).

Kinematic assessment

The stair negotiation was recorded using the Qualisys Track Manager (Qualisys AB®, Sweden), with eleven optoelectronic cameras (eight Oquos500, three MiqusM3), one Miqus video camera, and two force plates (FP4060-08/10, Bertec®). Kinematic data was collected at a 100Hz frequency.

Stair negotiation was performed in a four-step staircase (step height: 16 cm, depth: 29 cm and width: 69 cm) (Figure 1). The topmost step of the staircase was labeled “Step 4”, and the subsequent steps were labeled “Step 3”, “Step 2” and “Step 1”. In order to successfully complete the stair ascent, participants had to stand in front of the staircase before the force plates, take the first step on level ground on the force plate 2, the second step on the force plate 1, and then ascent three stairs using a step-over-step sequence at their own leisure (Novak & Brouwer, 2011). Each participant was informed on how to descent the staircase, which included starting at the step 4 in an upright stance with their feet side by

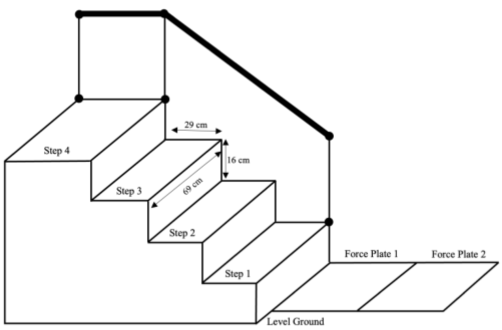

Figure 1: Scheme of stairs ascent and descent and transitions with the floor setup.

side and moving down at their own self-selected initiating limb and velocity (Buckley et al., 2013; Singhal et al., 2014). Additionally, participants were told to keep walking over the force plates for at least two steps after they reached level ground (Moniz-Pereira et al., 2018). When participants reached a standing position on level ground, the trial was considered over (Buckley et al., 2013). Throughout the testing, handrails were installed as a safety measure, however, participants were told not to use them unless absolutely essential. Prior to the experimental trial, all participants had a stair ascent and descent practice trial to increase their familiarity with the protocol. A total of three valid trials were recorded for each participant (Kováčiková et al., 2021). A trial was considered valid when the participant performed stair ascent and descent according to the previous indications without using the handrails for support.

Data processing

Qualisys Track Manager software (Qualisys AB®, Sweden 2020.3) was used to process marker trajectories of the three trials per participant, including the interpolation with linear, polynomial, and relational calculations of trajectory gaps. The data was then exported to Visual3D Professional™ (C-Motion, Inc., EUA), which computed the full-body biomechanical model adapted from the collaboration between Instituto Ortopedico Rizzoli and other authors (Leardini et al., 2011), adding the head segment and Rab Upper Extremity Model (Petuskey et al., 2007).

The joint angles were calculated using Cardan sequence that assumes that the x axis is in the medial–lateral direction, the y axis is anterior–posterior, and the z axis is in the up and down or axial direction. Accordingly, for the hip joint flexion (+), extension (-), adduction (+), abduction (-), internal rotation (+), external rotation (-), the knee joint flexion (+), extension (-), varus (+), valgus (-) and internal rotation (+), external rotation (-), and for the ankle joint dorsiflexion (+), plantarflexion (-), adduction (+), abduction (-), and eversion (+), inversion (-).

To characterize the sequences of walk to ascending and descending stairs to walk, the values from cycle time (seconds), speed (meters per second), and peak vertical velocity from the CoM (absolute value in meters per second) were computed.

The complete daily activity sequences of walking to ascent stairs and descending stairs to walk were divided into subtasks, specifically stairs use (stair ascent and descent) and floor transitions (F-S and S-F). Thus, two distinct cycles were identified for stair ascent and descent. For the ascending stairs task one stair cycle began in step 1 and ended in step 3 and another began in step 2 and ended in step 4. The descending task cycles were defined in the opposite direction (Figure 2). The transition F-S was considered as the instant the foot left the floor and ended when the foot left the step, with the opposite

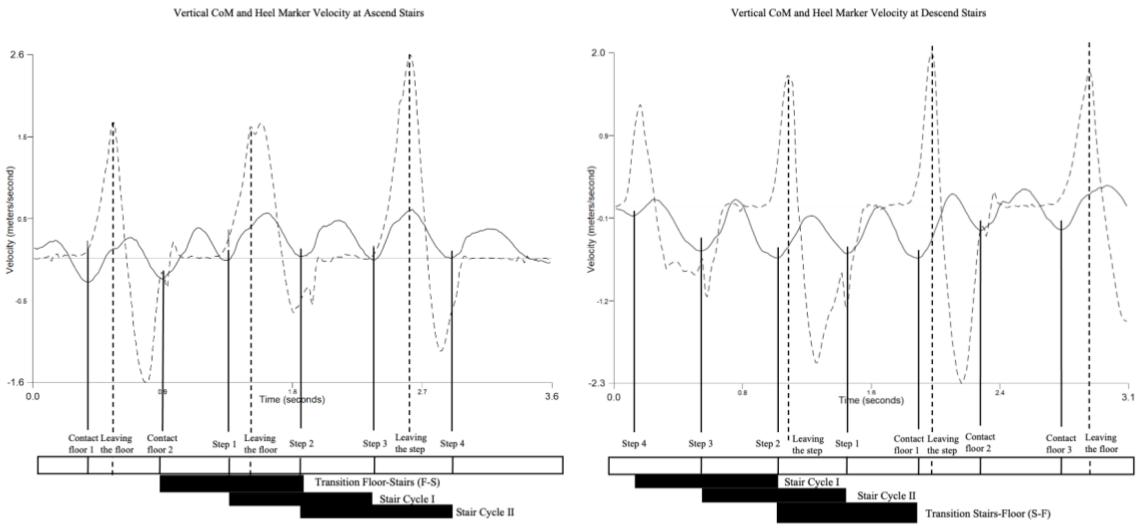

Figure 2: Events definition for each task, stair ascent and stair descent and respective transitions with the floor F-S and S-F. The regular line represents vertical CoM velocity and the dashed line represents the vertical heel marker velocity.

transition (S-F) following the reverse pattern (Figure 2). The moment of leaving the step or the ground was defined by the maximum heel marker's vertical velocity, and the moment of contact with the step or the ground was determined by the minimum downward CoM velocity (Foster et al., 2019). These events were validated through visual inspection.

Processing Joint Position and Velocities at Events

During both stair cycles and the S-F and F-S transitions, data on position and angular velocity of the hip, knee, and ankle joints, were extracted from the ipsilateral limb performing the contact with the step/floor and the moment the foot left the step/floor. Accordingly, the variables selected were position and angular velocity of hip, knee and ankle according to the three axes (X, Y, Z) at the contact with step and leaving the step at ascent and descent stairs and the contact with floor and leaving the floor at the F-S and S-F transitions.

Processing Joint ranges of motion and velocities, CoM displacement and velocity range at cycles

The ROM was calculated as the difference between the maximum and minimum lower limb angles during the stair ascent and descent cycles and F-S and S-F transition cycles. The difference between the maximum and minimum angular velocities of the lower limb joints was defined as ΔVelocity. Furthermore, the displacement of the CoM(CoM displacement) and CoM ΔVelocity in the three planes (X, Y, Z) was also computed for both the stair cycles and the S-F and F-S transitions.

Statistical analysis

The statistical software G*Power 3.1.9.7 was used to determine a 0.948 power (1- β), introducing as independent variables the significance level (α=0.05), effect size (f=0.6667), and sample size (n=60) (Kang, 2021).

The IBM SPSS 28.0 statistical package (SPSS Inc.) was used to compile the data and for statistical analysis. The normality of the distribution was assessed by the Kolmogorov-Smirnov and Shapiro-Wilk tests for the group of older adults without and with disability, respectively. Between-group comparisons of demographic and clinical characteristics were conducted using Mann-Whitney tests or Independent sample t-test. Chi-squared tests were used to evaluate between-group association in the distribution of the categorical variables, namely sex and history of fall, and self-reported health status.

Individual principal component models (PCMs) were made for different sets of variables. Particularly PCM I included the position and velocity of the hip, knee, and ankle on the three planes (X, Y, Z) at the moment of contact with step at stairs ascending and descending, and PCM II the same parameters at the moment the foot left the step during stair ascending and descending. The PCM V and VI included the same set of variables at contact with floor and leaving the floor moments, respectively, during the transitions S-F and F-S. PCM III was computed for ROM and and ΔVelocity of hip, knee, and ankle on the three planes at the stairs ascent and descent and PCM VII for the same set of variables at transitions S-F and F-S. Additionally, PCMs IV and VII were conducted for COM displacement and ΔVelocity on stairs and transition to floor cycles respectively (Figure 3). PCA was carried out utilizing the correlation matrix to guarantee that every variable contributed equally to the analysis, accordingly Z-scores were utilized to account for the varying measurement scales of the variables. The correlation matrix is based on standardized values, meaning that each variable was divided by its standard deviation, effectively normalizing the variables to have a mean of 0 and a standard deviation of 1. This step ensures that variables with different units and every variable contributed equally to the analysis. The suitability of the dataset for PCA was evaluated using Kaiser-Meyer-Olkin (KMO), as a measure of sampling adequacy for the overall data, and Bartlett's Test of Sphericity as a measure of data suitability for reduction**.** A significant Bartlett's Test (P<.05) and KMO values larger than 0.5 were used to determine whether the data were suitable for PCA. Potential outliers were manually inspected in the data and verified not to unduly influence the PCA results. Using eigenvalues greater than 1 as the criterion, the principal components (PCs) that accounted for the majority of the variance were extracted, ensuring that only meaningful variance contributors were retained for biomechanical interpretation. To aid in the interpretability of the components, a Varimax rotation was applied to redistribute variance across PCs, making it easier to identify biomechanical patterns. The rotated component matrix was examined to identify clusters of variables that loaded onto the same components. The components were interpreted based on the variables that exhibited high loadings (loading > 0.7, as the sample is n=60 (Hair et al., 1998)) on each component. The differences between the older adults with and without disability indicators for each of the PCs of a PCM was assessed using the non-parametric test Mann-Whitney U**,** with significance level set at .05.

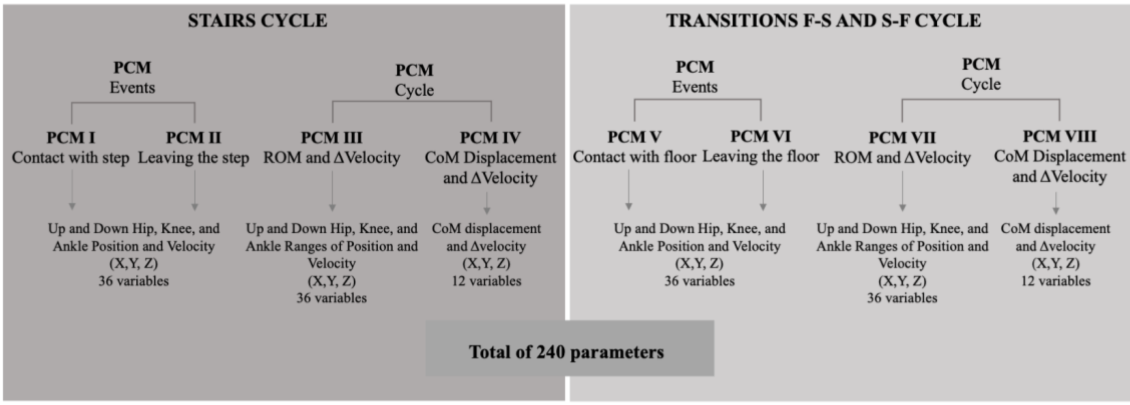

Figure 3: Parameters included in each PCM, divided by the subtasks stairs and transitions with the floor.

3. Results

Sample and tasks characterization

A total of 62 individuals, from 147 older adults, enrolled in the study as shown in Figure 4. During the evaluation two participants exhibited symptoms that affected the activities performance. As a result, 60 participants were included in the analysis of the study. Table 1 provides a summary of the descriptive statistics of their clinical and demographic features.

In examining the factors serving as markers for disability, substantial differences were observed between groups with and without disability (Table 1). Older individuals with disabilities exhibited poorer independence in activities of daily living (ADL) and instrumental activities of daily living (IADL) (P=.013 and P=.002, respectively), as well as reduced hand grip strength (P=.018) and diminished time spent in a one-leg stand posture (P<.001). Furthermore, in comparison to the non-disabled group, older persons with disabilities rated their health as poorer (P<.001). Polypharmacy also showed significant disparity between the groups (*P*<.001), with forty-four percent of older adults in the disability group consuming four or more medications per day.

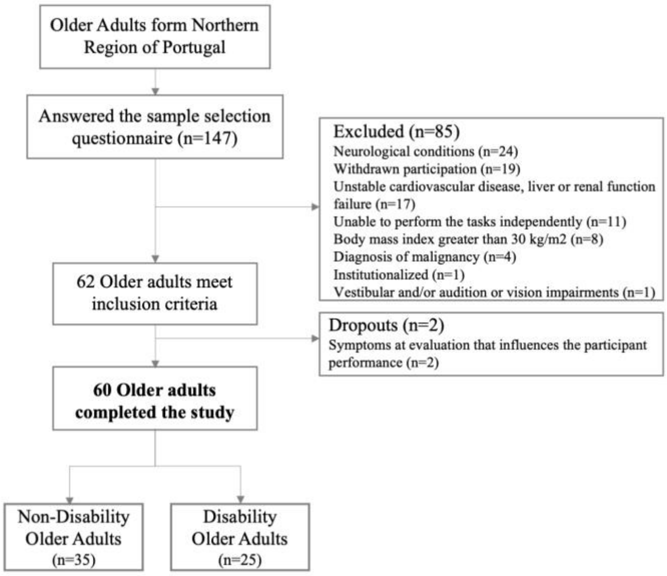

Figure 4: Flowchart of sample selection process.

Table 1: Demographic and clinical characterization of the sample. Data represented by the mean standard deviation (SD) for age, BMI, cognitive function, self-reported physical activity, hand grip strength, one leg standing time, ADL and IADL independence, and frequencies for history of falls in the previous 12 months, polypharmacy, and self-reposted health status. The p-value reflects the comparison between older adults without disability (ND) and Older adults with Disability (D).

		ND (n=35)	D (n=25)	*P*-value (Test Value)
Age (years)		66.34±5.60	68.60±6.77	.147(534)[a]
Gender (n female; %)		19; 54.29	19; 76	.085 (2.961)[b]
BMI (kg/m^2)		25.22±3.08	26,02±2,66	.298 (-1.049)[c]
History of fall in the previous 12 months (n fallers/%)		11 (31.4)	11 (44)	.469 (0.525)[b]
Polypharmacy (n polymedicated/%)		2 (5.71)	11 (44)	<.001 (12.595)[b]
Cognitive function (MMSE score)		28.94±1.31	28.68±1.49	.495(394)[a]
Self-reported physical activity (IPAQ MET-min/week)		3186.46±2964.91	3519.66±2822.11	.509 (393.5)[(a)]
Self-Reported Health	Poor	8 (22.86)	21 (84)	<.001 (21.832)[b]
	Good	27 (77.14)	4 (16)	
Hand grip strength (Kg)		36.59±39.86	25.07±7.54	.018 (279.5)[a]
One Leg Standing time (seconds)		38.83±20.93	18.19±20.72	<.001 (192.5)[a]
ADL independence (Barthel Index score)		19.97±0.17	19.76±0.44	.013 (345)[a]
IADL independence (Lawton & Brody score)		23±0.00	21.96±2.67	.002 (332.5)[a]

[a]Mann-Whitney U test; [b]Chi-square test; [c] Independent samples t-test

Regarding stair negotiation, older adults with disabilities demonstrated a longer cycle time (*P*=.003), reduced speed (*P*<.001), and lower peak vertical velocity of the center of mass (CoM) (*P*=.003) while ascending stairs (Table 2). In the descending stairs task, older adults with disabilities exhibited lower speed (*P*<.009) and CoM peak velocity (*P*<.013).

Table 2: Walk to ascending stairs and descend stairs to walk tasks characterization according to cycle time, double limb support time, speed and CoM peak velocity mean and standard deviation. The p-value reflects the comparison between older adults without disability (ND) and older adults with disability (D).

	Walking to ascend Stairs			Descending Stairs to walk		
	ND	D	*P*-value (test value)	ND	D	*P*-value (test value)
Cycle time (seconds)	1.15±0.23	1.31±0.16	.003 (-2.876)[a]	1.13±0.21	1.22±0.16	.06 (562.0)[b]
Speed (meters per seconds)	0.68±0.11	0.60±0.08	<.001 (3.278)[a]	0.86±0.18	0.76±0.14	.009 (2.450)[a]
CoM peak vertical velocity (meters per seconds)	0.20±0.05	0.17±0.03	.003 (-2.853)[a]	0.56±0.07	0.52±0.08	.013 (-2.284)[a]

[a] Independent samples t-test; [b] Mann-Whitney U test

Principal component analysis models

The study involved the computation of PCMs to analyze the position and velocity of the hip, knee, and ankle on the three axes (X,Y, Z) at the moment of contact with step (KMO=0.507), and at the moment the foot left the step (KMO=0.502) during stair cycle, and at the same events during the transition to floor cycle, (KMO=0.531 and KMO=0.500, respectively). PCM were also computed for a range of motion and velocity range from hip, knee, and ankle on the three axes (X.Y, Z) at the stair (KMO=0.621) and transition to floor (KMO=0.620) cycles. Additionally, PCMs were conducted for COM displacement and ΔVelocity on stairs (KMO=656) and transition to floor cycles (KMO=0.714). Bartlett's Test of Sphericity was significant (*P*<.001) for all PCMs, indicating that the data was suitable for dimensionality reduction. Table 3 provides a detailed description of the PCs with eigenvalues greater than 1 for each of the PCMs.

Table 3: Principal component models (PCM), principal components (PC), variance explained and P-value corresponding to a Mann-Whitney U test comparing the PC scores between older adults without (ND) and with (D) disability.

Variables included in the PCM	PC	Variance explained (%)	Cumulative variance explained (%)	Median and Interquartile Range of Z scores		*P*-value
				ND	D	
Stairs						
PCM I Hip, Knee, Ankle Position and Velocity (X, Y, Z) at Contact with step (36 variables included)	1	16.40	16.40	-0.06 (1.16)	0.08 (1.15)	.910
	2	14.45	30.85	-0.07 (1.37)	0.21 (1.32)	.311
	3	9.93	40.77	0.25 (1.15)	-0.08 (1.38)	.431
	4	8.11	48.88	-0.15 (1.40)	0.55 (1.11)	.002
	5	7.95	56.83	-0.03 (1.21)	0.25 (2.30)	.747
	6	6.75	63.58	0.32 (1.42)	-0.32 (0.89)	.144
	7	5.34	68.92	-0.36 (1.24)	0.02 (1.44)	.066
	8	4.68	73.60	-0.17 (1.21)	0.07 (1.68)	.534
	9	3.86	77.46	0.05 (1.10)	-0.11 (1.57)	.669
	10	3.57	81.04	-0.19 (1.38)	0.07 (1.46)	.081
	11	3.29	84.33	-0.01 (1.46)	-0.06 (1.65)	.910
PCM II Hip. Knee. Ankle Position and Velocity (X, Y, Z) when Leaving the step (36 variables included)	1	19.44	19.44	0.02 (1.11)	-0.17 (1.06)	.364
	2	15.27	34.71	0.29(1.16)	-0.50 (1.15)	.008
	3	11.00	45.70	0.24 (1.26)	-0.27 (1.24)	.007
	4	9.20	54.90	-0.01 (1.10)	0.15 (1.91)	.647
	5	7.26	62.16	0.29 (1.11)	-0.15 (1.36)	.216
	6	6.59	68.74	0.00 (1.64)	0.36 (1.05)	.058
	7	4.94	73.68	0.12 (1.42)	-0.03 (1.66)	.691
	8	3.96	77.65	-0.08 (1.57)	0.33 (1.08)	.341
	9	3.83	81.47	-0.31 (1.45)	-0.07 (1.21)	.805
	10	2.95	84.42	-0.06 (1.59)	0.07 (1.22)	.414
PCM III Hip, Knee, Ankle ROM and ΔVelocity (X, Y, Z) (36 variables included)	1	21.18	21.18	0.29 (1.25)	-0.54 (1.12)	.026
	2	20.10	41.28	-0.23 (0.66)	-0.04 (0.68)	.270
	3	11.64	52.92	-0.19 (1.00)	-0.15 (0.77)	.840
	4	7.03	59.95	0.05 (1.42)	0.10 (1.48)	.356
	5	6.36	66.31	-0.13 (0.96)	-0.34 (1.93)	.691
	6	5.04	71.35	0.04 (1.51)	-0.30 (1.20)	.440
	7	3.60	74.95	-0.26 (1.06)	0.09 (1.72)	.440
	8	3.41	78.36	0.16 (1.61)	0.09 (1.36)	.505
	9	3.11	81.47	0.03 (1.42)	-0.16 (1.34)	.781
	10	2.81	84.29	-0.28 (1.18)	0.17 (1.28)	.018
PCM IV CoM Displacement and ΔVelocity (X, Y, Z) (12 variables included)	1	32.97	32.91	0.17 (1.39)	-0.51 (1.37)	.014
	2	17.28	50.25	0.10 (1.35)	-0.35 (1.02)	.068
	3	10.38	60.63	-0.11 (1.36)	0.13 (1.04)	.495
	4	10.01	70.64	-0.28 (1.31)	0.12 (1.43)	.205
Transitions S-F and F-S						
PCM V	1	18.07	18.07	-0.03 (1.11)	-0.11 (1.28)	.910
	2	14.48	32.55	0.03 (1.29)	-0.23 (1.27)	.574

Hip, Knee, Ankle Position and Velocity (X, Y, Z) at Contact with floor (36 variables included)	3	10.34	42.90	0.33 (1.71)	-0.35 (0.99)	.039
	4	8.44	51.34	0.05 (1.57)	-0.43 (1.07)	.277
	5	7.40	58.74	0.07 (1.60)	-0.10 (1.24)	.505
	6	6.19	64.93	-0.11 (1.48)	0.14 (1.47)	.958
	7	5.00	69.93	-0.12 (1.06)	0.06 (1.79)	.680
	8	4.81	74.74	0.10 (1.18)	0.06 (1.24)	.725
	9	3.68	78.42	0.21 (1.03)	0.00 (1.49)	.185
	10	3.02	81.44	-0.07 (1.58)	0.19 (1.69)	.793
PCM VI Hip, Knee, Ankle Position and Velocity (X, Y, Z) when Leaving the floor (36 variables included)	1	19.81	19.81	0.09 (1.31)	-0.28 (1.14)	.258
	2	15.93	35.73	-0.17 (1.13)	0.34(0.90)	.033
	3	10.06	45.79	-0.41 (1.93)	0.33 (1.24)	.031
	4	7.54	53.34	0.39 (1.65)	-0.09 (1.26)	.333
	5	6.86	60.19	0.16 (1.49)	-0.07 (1.57)	.467
	6	6.42	66.61	-0.07 (1.21)	-0.02 (2.00)	.982
	7	5.23	71.83	-0.12 (0.91)	0.09 (1.31)	.887
	8	4.63	76.47	0.03 (1.41)	0.17 (1.05)	.389
	9	4.18	80.65	-0.19 (1.28)	0.35 (1.21)	.006
	10	2.79	83.44	0.10 (1.35)	0.01 (1.63)	.680
PCM VII Hip, Knee, Ankle ROM and ΔVelocity (X, Y, Z) (36 variables included)	1	25.12	25.12	0.29 (1.08)	-0.19 (1.39)	.030
	2	16.62	41.74	0.09 (1.48)	-0.06 (1.33)	.195
	3	12.40	54.14	-0.19 (0.52)	-0.42 (1.17)	.647
	4	7.62	61.76	-0.13 (0.80)	-0.17 (0.79)	.982
	5	6.54	68.30	-0.14 (0.67)	-0.07 (0.71)	.554
	6	5.90	74.20	-0.12 (1.24)	-0.15 (0.99)	.725
	7	4.18	78.37	-0.15 (1.22)	-0.06 (1.44)	.647
	8	3.64	82.02	-0.31 (1.33)	0.04 (1.33)	.691
PCM VIII CoM Displacement and ΔVelocity (X, Y, Z) (12 variables included)	1	30.358	30.36	0.18 (1.13)	-0.31 (1.31)	.083
	2	19.058	49.42	-0.32 (1.84)	0.02 (0.98)	.047
	3	13.274	62.69	-0.26 (1.38)	0.06 (1.65)	.405

The study observed statistically significant differences between older adults with and without disabilities in twelve principal components (PCs) across PCM I to VIII. After applying Varimax rotation, the components were interpreted based on the variables with loadings exceeding 0.7, as outlined in Table 4. Analysis of the variables with higher loadings in the PCs revealed a prevalence of variables associated with angular velocity, distributed similarly during ascending and descending tasks, particularly in the sagittal plane. Notably, the contact of the foot with the step was found to be important in the ascending task regarding frontal hip angular velocity and sagittal knee velocity (PCM I). Additionally, significant differences between groups were demonstrated in two PCs at the moment of leaving the step (PCM II), one defining the ascending (PC2) and other the descending (PC3) tasks. Position and angular velocity on sagittal plane of hip, and knee and ankle angular velocity are present in PC 2, with higher loadings for the ones related to the knee joint. The PC3, defining the descending task retained the hip, knee and ankle angular velocities in the sagittal plane. The range of motion and the range of angular velocities were divided into the planes sagittal and frontal, with PC1 retaining sagittal hip ROM and Δvelocity and knee Δvelocity when descending stairs and hip and knee ΔVelocity when ascending stairs. The PC 10 retained frontal plane ROM of ankle joint during descending (PCM III).

The PCM V analyzing transitions from and to stair negotiation, regarding the contact moment, retained only variables of the S-F transition, particularly, frontal and transverse hip angular velocity and transverse knee angular velocity. At the moment of leaving the floor (PCM VI), three PCs demonstrated differences between groups, gathering variables of S-F and F-S transitions. PC2 presented higher loadings in angular velocities of the S-F transition of the transverse plane in the hip joint and sagittal and transverse planes in the ankle joint. This component also presented higher loading for the transverse ankle velocity in the F-S transition. PC3 retained F-S sagittal hip and knee velocities, as PC 9 retained frontal hip angles of both F-S and S-F transitions. The PCM VII, computed for ROM and Δvelocity of transitions, demonstrated significant differences between groups only in PC1, which explained 25% of the total variance. The variables with higher loadings were all of the sagittal planes (S-F hip and knee ROM and ΔVelocity, and F-S hip ΔVelocity and knee ROM and ΔVelocity). The variables with higher loadings were all of the sagittal plane (S-F hip and knee ROM and ΔVelocity, and F-S hip ΔVelocity and knee ROM and ΔVelocity). In analyzing both stair ascent and descent cycles as well as transitional movements, the parameters most consistently preserved were the angular velocities of the hip and knee in the sagittal plane. Accordingly, the complete cycle for the groups without and with disability is plotted in Figure 5.

The CoM displacement and ΔVelocity PCM IV built with stairs cycle data demonstrated differences between older adults with and without disability in PC 1 explained approximately thirty-three percent of the variance, and retained displacement and ΔVelocity of CoM in sagittal plane both in ascend and descend stairs. The PC2 of PCM VIII, computed with the CoM data of transition to floor cycles, presented differences between the groups, retaining the variables considering the transverse plane except for CoM displacement in the transition S-F. The detailed mean and standard deviation of all variables assessed on stairs and F-S and S-F cycles can be found in Tables S1 to S4 of the supplementary material (Appendix XVI).

Table 4: Variables with loadings higher than 0.7 of the principal components (PC) that presented significant differences between older adults without (ND) and with disability (D), with respective mean and standard deviation of each group. The tasks ascending stairs and descending stairs are designated Up and Down, respectively.

PCM	**PC**	**Variable**	**Load**	**Mean ± Standard Deviation**	
				ND	**D**
Stairs					
PCM I (contact with step)	4	Up Hip Velocity (Y)	0.814	18.7±22.0	10.3±20.5
		Up Knee velocity (X)	0.888	-140.2±62.2	-89.1±42.9
PCM II (leaving the step)	2	Up Hip Angle (X)	0.750	34.7±12.7	30.4±11.4
		Up Hip Velocity (X)	0.784	199.7±43.2	168.7±36.1
		Up Knee Angle (X)	0.811	58.4±11.6	49.7±12.7
		Up Knee Velocity (X)	0.847	392.5±91.4	336.5±63.9
		Up Ankle Velocity (X)	0.744	128.0±87.0	84.9±79.4
	3	Down Hip Velocity (X)	0.804	153.0±43.4	113.5±35.1
		Down Knee Velocity (X)	0.877	283.2±86.2	197.0±87.3
		Down Ankle Velocity (X)	-0.853	-212.6±50.8	-160.0±58.8
PCM III (Up and down Cycles)	1	Up Hip ΔVelocity (X)	0.856	316.5±45.4	286.3±35.1
		Up Knee ΔVelocity (X)	0.901	651.1±112.3	587.0±83.8
		Down Hip ROM (X)	0.803	27.8±4.0	27.0±3.0
		Down Hip ΔVelocity (X)	0.853	295.8±85.4	239.5±45.4
		Down Knee ΔVelocity (X)	0.807	690.6±138.0	570.7±97.2
	10	Down Ankle ROM (Y)	0.867	12.4±2.8	14.4±3.3
PCM IV (Up and down cycles)	1	Up CoM displacement (X)	0.824	0.05±0.01	0.04±0.01
		Up CoM ΔVelocity (X)	0.855	0.22±0.05	0.19±0.04
		Down CoM displacement (X)	0.820	0.05±0.01	0.04±0.01
		Down CoM ΔVelocity (X)	0.801	0.31±0.06	0.30±0.05
Transitions F-S and S-F					
PCM V (contact with floor)	3	S-F Hip Velocity (Y)	0.852	7.2±21.3	-8.7±15.0
		S-F Hip Velocity (Z)	-782	-12.3±23.2	-5.4±18.8
		S-F Knee Velocity (Z)	0.841	10.3±40.0	-8.8±28.9
PCM VI (leaving the floor)	2	F-S Ankle Velocity (Z)	-0.746	4.7±10.3	-4.8±16.6
		S-F Hip Velocity (Z)	0.788	-14.6±35.1	0.7±29.5
		S-F Ankle Velocity (X)	0.718	-230.4±61.8	-168.0±63.1
		S-F Ankle Velocity (Z)	-0.816	4.2±32.7	-10.9±30.1
	3	F-S Hip Velocity (X)	-0.857	142.2±34.0	130.0±24.2
		F-S Knee Velocity (X)	-0.929	234.3±116.5	192.1±97.6

	9	F-S Hip Angle (Y)	0.784	1.8±2.9	3.7±2.4
		S-F Hip Angle (Y)	0.901	3.1±3.4	4.8±3.4
PCM VII (F-S and S-F cycles)	1	S-F Hip ROM (X)	0.747	46.1±7.0	46.3±6.0
		S-F Hip ΔVelocity (X)	0.861	296.6±63.6	274.7±50.1
		S-F Knee ROM (X)	0.789	75.5±4.4	73.4±4.4
		S-F Knee ΔVelocity (X)	0.888	750.6±130.3	652.7±114.1
		F-S Hip ΔVelocity (X)	0.865	329.4±59.1	297.7±47.4
		F-S Knee ROM (X)	0.795	70.2±6.6	67.7±5.7
		F-S Knee ΔVelocity (X)	0.907	658.5±122.5	575.0±91.6
PCM VIII (F-S and S-F cycles)	2	Up CoM displacement Z	0.710	0.22±0.01	0.22±0.01
		Up CoM ΔVelocity Z	0.833	0.60±0.10	0.65±0.08
		Down CoM ΔVelocity Z	0.798	0.31±0.06	0.30±0.05

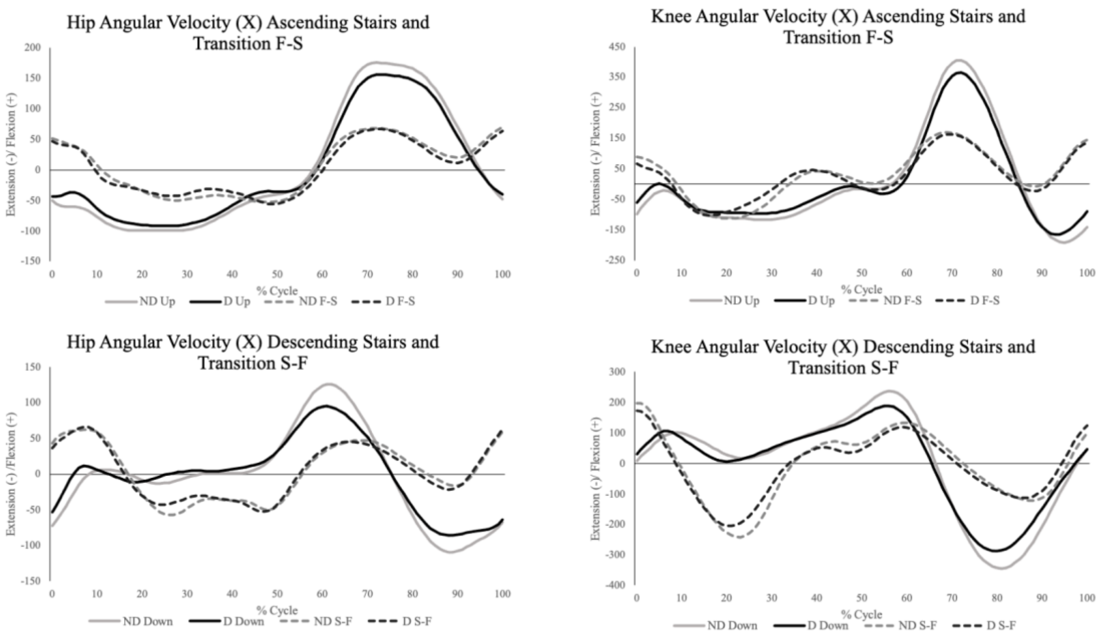

Figure 5:Sagittal hip and knee angular velocities on ascending stairs (Up) and transition F-S and descending stairs (Down) and transition S-F, within the cycle for older adults without (ND) and with (D) disability.

4. Discussion

Principal Results and Comparison with Prior Work

The present study investigated the kinematic differences in joint angles, joint velocities, and CoM displacement during stair ascent, descent, and floor-to-stair (F-S) and stair-to-floor (S-F) transitions among older adults with and without disability. This study is believed to be the first to delve into the distinguishing parameters of kinematics between older adults with and without disability when negotiating stairs and transitions to the floor. As hypothesized, older adults with disabilities demonstrated significant differences in characterization parameters during stair ascent to walk and stair descent to walk, particularly in cycle time, speed, and CoM vertical peak velocity when compared to their non-disabled counterparts.

In this study the time taken to walk to ascent stairs was significantly longer in older adults with disability. This contrasts with previous research, such as the study by Oh-Park, Wang et al. (2011), which considered stair descent time, but not ascent time, as a predictor of functional decline (Oh-Park, Wang, et al., 2011). This difference may be attributed to the fact that the participants in the study by Oh-Park, Wang et al. (2011)(Oh-Park, Wang, et al., 2011) commenced the task in front of the stairs, whereas the current study evaluated stair negotiation and the transition to the floor, beginning and ending with walking. This approach is more challenging and reflective of real-life activities, as highlighted in the study by Vallabhajosula, Yentes et al. (2012) (Vallabhajosula et al., 2012). In addition to a longer time to complete the ascending task, older adults with disabilities also demonstrated reduced speed, and lower CoM peak velocity while walking to ascent stairs and descending stairs to walk. This is consistent with a more conservative strategy that could reduce the risk for a fall that was identified in older adults compared to younger adults (Buckley et al., 2013), which seems to be augmented in older adults with disability. In addition to the characterization parameters of the tasks, the study encompassed a comprehensive analysis of a wide array of variables, including those related to the position and velocity of lower limb joints, CoM displacement and velocity in three axes, and the description of two tasks: ascending and descending. These tasks were further subdivided into sub-tasks, particularly using stairs and transitioning to the floor, and were characterized at two distinct moments: contact with the step or floor and leaving the step or floor, along with their respective ranges. Given the complexity and multidimensionality of the dataset, a PCA approach was deemed appropriate. PCA was employed to elucidate the shared variance of the parameters associated with stair negotiation, thereby identifying a simplified representation that consolidates the most significant parameters. This approach simplifies the analysis of stair negotiation in older adults with disability. While the mechanics of successful stair negotiation for healthy older adults have been extensively documented (Jacobs, 2016), studies focusing on older adults with disability have predominantly centered on measuring the time taken to complete tasks (Oh-Park, Wang, et al., 2011). The present study sought to assess the aforementioned set of parameters to gain a comprehensive understanding of the behavior of older adults with disability during stair negotiation. Moreover, it is fundamental to consider different axes, as previous studies have shown that factors in the sagittal plane are crucial (Novak & Brouwer, 2011; Novak et al., 2011; Reeves et al., 2008), and limited studies have compared older adults to younger individuals in terms of the frontal and transverse planes (Mian et al., 2007; Nadeau et al., 2003). Furthermore, the PCA analysis was instrumental in reducing and analyzing the data curves of knee angles, moments, and forces in a study by Reid, Graha et al. 2010 (Reid et al., 2010). That decision was informed by existing literature, which has highlighted the direct relationship between functional impairment during stair negotiation and the knee joints of older adults compared to their younger counterparts (Reid et al., 2010). In line with this rationale, a conservative approach was adopted in the present study, entailing the analysis of discrete data collected at different events as an initial step in exploring the task of stair negotiation among older adults with disability. By focusing on discrete events rather than continuous data, our PCM approach provides a more granular analysis of stair negotiation mechanics. Accordingly, the use of individual PCMs allowed us to target specific, biomechanically meaningful parameters in the stair negotiation cycle, such as angular velocity, especially within the sagittal plane. In the cycles of stair ascent and descent, both the instances of foot contact with the step and subsequent lift-off were marked by significant retention of hip and knee sagittal angular velocity in the PCMI and PCMII. This significance was further highlighted by the range analyses conducted in PCMIII, which preserved the ranges of sagittal angular velocities of the hip and knee joints during both ascending and descending tasks. Notably, older adults with disability demonstrated lower mean sagittal angular velocities at the hip and knee joints compared to their non-disabled peers. This disparity is visually represented in Figure 5, which indicates that while older adults with disabilities exhibit movement patterns similar to those of non-disabled older adults, they tend to adopt more conservative movement strategies. These findings align with previous aging research, which demonstrated that knee joint angular velocity at the point of maximal knee joint moment demand during the stride cycle was significantly lower in older adults compared to younger adults, a pattern not observed for ankle joint angular velocity (Reeves et al., 2008, 2009). These studies also found that variation in knee extension-flexion angles and ankle plantarflexion–dorsiflexion angles during stair ascent (Reeves et al., 2009) and descent (Reeves et al., 2008) was comparable between young and older adults, consistent with our observations among older adults with and without disability. Prior research on stair descent also indicated reduced knee ROM in the sagittal plane and increased hip ROM in the frontal and transverse planes in older adults compared to younger adults (Mian et al., 2007). It is hypothesized that older adults may rely more on ankle movements to maintain stability, especially in the frontal plane, as a balance-preserving strategy that can help manage potential mediolateral instability on descending stairs compared with younger adults (Mian et al., 2007; Startzell et al., 2000). In the present study, although lower limb joint positions did not appear to be predominant in stair descent, the PCA indicated that older adults with disabilities descended stairs with lower sagittal hip ROM and higher frontal ankle ROM suggesting that older adults with disability further use this strategy compared with those without disability.

Within the F-S and S-F transition cycles, the hip and knee sagittal angular velocity variables were also retained. Additionally, hip angular velocity in the transverse plane was notably retained at the moments of floor contact and leaving the floor during these transitions. The emergence of variables associated with frontal and transverse planes in F-S and S-F transitions aligns with previous findings indicating that older adults exhibit reduced independent control of adjacent joints during these transitions compared to younger adults (Chiu et al., 2015). Moreover, the hip angle in the frontal plane was higher in older adults with disability in F-S and S-F transitions. The transitioning from level gait to stair and the opposite necessitates a shift in motor control between these tasks (Di Giulio et al., 2020), that seems to be significantly more impaired in older adults with disability.

CoM parameters associated with mediolateral displacement and velocity were retained within the stair cycle. In contrast, during the F-S and S-F transition cycles, the retained parameters predominantly described vertical displacement and velocity, except for F-S transition velocity. Buckley et al. (2013) proposed that reduced peak downwards CoM velocity of older participants may result from stiffening the limb, prolonging limb flexion when lowering the CoM (Buckley et al., 2013). This effect may be amplified in older adults with disability, according to our findings. Additionally, Nadeau et al. (2003) observed that mediolateral CoM control demands are greater during stair negotiation than during level walking, corroborating the critical role of CoM parameters in influencing stair negotiation dynamics (Nadeau et al., 2003).

Given that stair use in the home environment can help older adults without disability retain the ability to perform IADL (Tomioka et al., 2018), these insights carry important implications for the development of targeted interventions aimed at supporting the stability and mobility of older adults, especially those with disability. These findings thus provide clinicians and researchers with actionable information to better address the unique mobility needs of this population, facilitating improvements in both safety and quality of life for older adults navigating stair environments.

Limitations

Despite the original contributions of this study, certain limitations are noted. Older adults with disability significantly take more medication than their counterparts. As the analysis of the medication type was not the object of this study, future studies should address that relationship since stair negotiation is influenced by medication intake (Mustafaoğlu et al., 2015). This study's PCA marks initial steps in stair negotiation analysis; future research should explore full waveform data of high-loading parameters to gain more comprehensive insights.

The findings of this study align with established literature on stair negotiation biomechanics in older adults, highlighting compensatory behaviors such as reduced sagittal velocities and conservative movement strategies. The unique contribution of this research lies in the detailed retention of kinematic parameters across various movement planes and phases, offering a more nuanced understanding of stability and movement adaptations in older adults with disability. By focusing on discrete events rather than continuous data, our PCM approach provides a more granular analysis of stair negotiation mechanics, identifying critical sagittal angular velocities of the hip and knee joints during stair ascent and descent, as well as frontal and transverse plane movements of these joints during stair to floor transitions. Additionally, this approach highlights the potential application of PCMs to the data curves for these parameters, enhancing its utility in both research and clinical contexts.

5. Conclusions

Overall, this study examined kinematic differences in joint angles, joint velocities, and CoM displacement and velocity between older adults with and without disabilities during stair ascent and descent. Transitional movements F-S and S-F were also analyzed. PCA of 240 kinematic variables led to the selection of 41 key parameters majorly related knee and hip joint angular velocity. In the cycles of stair ascent and descent, both the foot contact with the step and subsequent lift-off were marked by significant retention of hip and knee sagittal angular velocity as well as respective angular velocity range. These parameters were also retained within the F-S and S-F transition cycles, in addition to the hip angular velocity in the transverse plane at the moments of floor contact and leaving the floor. For the stair cycle, CoM parameters were largely linked to mediolateral displacement and velocity range, while during F-S and S-F transitions, parameters describing vertical displacement and velocity were predominant, except for F-S transition velocity.

The findings from this study provide valuable insights that could inform disability prevention initiatives. This PCA approach represents a foundational step in understanding stair negotiation in older adults, and further research should focus on full waveform data of high-loading parameters to provide a more comprehensive understanding.

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Authors' contributions

CRediT authorship contribution statement

Juliana Moreira: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Validation; Visualization; Writing - original draft, review & editing.

Ivone Teles, José Félix, Diana C. Guedes, Leonel A. T. Alves: Validation, Investigation, Data curation, Writing – original draft, review.

Bruno Cunha: Formal analysis, Writing- review, Validation.

Rubim Santos – Writing - review, Validation, Supervision, Project administration.

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Ethics statement

The study adhered rigorously to the principles outlined in the Declaration of Helsinki. All participants received information about the study's purpose and methodology, and they completed an informed consent form. The study was submitted to the Institutional Ethics Committee on April 27, 2022, and obtained authorization on May 25, 2022 (Approval No CE0064C).

Conflicts of Interest

None declared.

Study VI - Sit-to-stand and stand-to-sit kinematics in older adults with and without functional disability: principal component analysis.

Submitted to a scientific journal

ABSTRACT

This cross-sectional study examined lower limb and trunk kinematics in adults aged 60+ with (n=25) and without (n=35) functional disability during Sit-to-Stand and Stand-to-Sit transitions. Principal component analysis assessed joint motion, angular velocity, and center of mass (CoM) displacement across movement phases. Both Sit-to-Stand and Stand-to-Sit biomechanical parameters were grouped into nine principal components (PCs). Sit-to-Stand variance was explained mainly by hip, knee, and trunk stabilization, while Stand-to-Sit variance was more distributed. Stand-to-Sit was the most discriminative for functional disability, with significant group differences emerging in two PCs, one including knee and hip kinematics and another trunk angular velocity.

Keywords: Biomechanical Phenomena, Factor Analysis, Geriatrics, Activities of Daily Living

1. Introduction

The ability to rise from a seated position and its reverse are representative and essential for several functional activities and losing such ability undermines an individual's functional independence (Kuo et al., 2010).

Age-related alterations in the neuromusculoskeletal and sensory systems render community-living older adults increasingly challenged by the transition from sitting to standing (Kuo et al., 2010). To perform sit-to-stand (Sit-TS) and stand-to-sit (Stand-TS), coordinated bilateral lower limb and trunk movements are necessary to raise the body's center of mass (CoM), while maintaining postural stability. In particular, Sit-TS movement involves major challenges for older adults because the lower limbs need to produce timely and adequate torques to move the body CoM forward and upwards within the limits of a base of support whose size is significantly reduced along the task (Sadeh et al., 2023).

A recent systematic review exploring biomechanical and neuromuscular control characteristics of Sit-TS transition in young and older adults reported that the older adults showed slower transfer time, increased trunk flexion and higher horizontal body sway (Sadeh et al., 2023). Previous studies described also lower average and peak velocity (Smith et al., 2020), and lower maximal knee extension in the older than in the younger adults (Lee et al., 2007). Complementary research applied principal component analysis (PCA) to the Sit-TS transition, focusing on the time series data of ankle, knee, hip, trunk, and head angles and angular velocities with and without hand support. Older adults performing Sit-TS, without hand support, showed reduced trunk movement, though PCA revealed no significant differences in angular velocity components (Haraguchi et al., 2023).

While aging movement-related adaptations have been described for Sit-TS transition, the Stand-TS transition has been less explored. Moreover, the association between aging movement related adaptations and disability remains poorly investigated. Thus, the aim of this study is to explore the kinematics of Sit-TS and Stand-TS transitions among older adults and investigate the differences in the domains between older adults with and without functional disability. This study presents a novel application of PCA to biomechanical analysis of Sit-TS and Stand-TS transitions offering insights into multidimensional kinematic domains that remain underexplored in the context of aging and functional disability. The findings aim to contribute valuable new information to disability assessment and prevention strategies for older adults.

Specifically, this study analyzes relevant overall task parameters including the time duration, CoM acceleration, and measures of anteroposterior (AP) and mediolateral (ML) postural sway of Sit-TS and Stand-TS will be considered to characterize and compare older adults with and without disability (Sadeh et al., 2023). The tridimensional lower limb joints and trunk range of motion, angular velocity, and the CoM displacement and velocity across different phases of Sit-TS and Stand-TS transitions will be considered for the determination of the Principal Component Models (PCMs). The principal components (PC) will be analyzed to differentiate older adults with and without disability.

2. Material and methods

2.1 Study design and participants

This cross-sectional study followed Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (Elm et al., 2008) guidelines, and is integrated in a larger study whose protocol is registered in ClinicalTrials.gov database (register identifier: NCT05611723).

The study was performed in Center for Rehabilitation Research of School of Health, Polytechnic of Porto. A sample selection questionnaire was disseminated in research center partner institutions between June 1st, 2022 and march 31st, 2023. Data collection took place at the research center between June 1st, 2022 and April 30th, 2023.

The study sample included older adults, 60 years or over, living in the community, and able to perform the tasks (gait, sit-to-stand, climb and descend stairs) independently. Volunteers were excluded from if they were institutionalized; had established diagnosis of malignancy or terminal diseases with an anticipated survival of less than 1 year; had stroke history, cerebral hemorrhage, head trauma, or Parkinson's disease; had cognitive impairment, specifically Mini Mental State Examination (Portuguese version) score of 22 for 0 to 2 years of literacy, 24 for 3 to 6 years of literacy and 27 for more than 6 years of literacy (Morgado et al., 2009); had rheumatic pathologies that interfere with the tasks performance; had diabetic foot, lower limb fracture less than 6 weeks, or other related conditions; had unstable cardiovascular disease, liver or renal function failure; had a body mass index greater than or equal to 30 kg/m^2; had vestibular and/or audition or vision impairments non corrected that influence the performance of tasks; or had the presence of symptoms at the time of evaluation that influenced the participant performance of tasks. Participants were divided into two groups: older adults without disabilities and those exhibiting two or more disability indicators identified in previous research (Moreira et al., 2022). These indicators included handgrip strength (measured using a handheld dynamometer), balance (assessed through single-leg balance test duration), overall self-reported health status (via a self-reported question), basic activities of daily living (ADL) (measured by the Barthel Index), and instrumental activities of daily living (IADL) (evaluated using the Lawton and Brody scale).

2.2 Instruments

The demographic data, health conditions, number of prescribed medications, history of falls within the previous 12 months, were all collected through a comprehensive questionnaire. Additionally, the Mini Mental State Examination (MMSE) results and the seven-item short version of the International Physical Activity Questionnaire (IPAQ) were also collected. The disability assessment tools collected included the Barthel Index of Activities of Daily Living, the Lawton & Brody Instrumental Activities of Daily Living Scale, and self-reported health (SRH) (Moreira et al., 2022). Handgrip strength and the One-Leg Standing Test (OLST) were used to further evaluate disability (Moreira et al., 2022). If two or more of these disability markers were fulfilled, older people were classified as having disability.

The kinematic and kinetic data was collected synchronously, using the Qualisys Track Manager (Qualisys AB®, Sweden) with twelve optoelectronic cameras (eight Oquos500, four MiqusM3), one Miqus video camera and two force plates (FP4060-08/10, Bertec®), at an acquisition rate of 100 Hz. An eighty-one reflective marker set up adapted from the collaboration between Instituto Ortopedico Rizzoli and other authors (Cappozzo et al., 1995; Leardini et al., 2011; Leardini et al., 2007), adding the head segment (C-motion, 2017) and Rab Upper Extremity Model (Petuskey et al., 2007). Data processing was wielded both on previous software as in Visual3D Professional (C-Motion, Inc., EUA).

2.3 Procedures and data collection

Firstly, demographic, anthropometric, characterization parameters and answer and performance of the disability indicators were collected. The kinematic data collection procedure included Sit-TS and Stand-TS tasks performance in an armless chair with 0.46 meters height. Participants with comfortable and usual footwear, with no heels, were instructed to stand up from a chair at a self-selected speed and with their arms folded across the chest. After three practice trials to locate the preferred foot position in the anteroposterior direction, participants were instructed not to move their feet during the test. After reaching the upright standing position, participants stood still for three seconds and then sat down again (Kuo et al., 2010; Lin & Lee, 2022). Participants were asked to perform the task three times, and a trial was valid if the participant complete the movements maintaining their balance (Lin & Lee, 2022).

2.4 Data processing

Each marker trajectory was identified and its accuracy during data collection was verified using the Qualisys Track Manager software (Qualisys AB®, Sweden). The biomechanical full body model was applied in Visual3D Professional (C-Motion, Inc., EUA), and a 6 Hz low-pass Butterworth filter was applied to markers trajectory data. A Cardan sequence was used, that assumes that the x axis is in the medial–lateral direction, the y axis is anterior–posterior, and the z axis is in the up and down or axial direction (Richards, 2018). Kinematic parameters computed included the time to perform each task, CoM peak acceleration for Sit-TS, CoM peak deceleration for Stand-TS, and anteroposterior (AP) and mediolateral (ML) postural sway both for Sit-TS and Stand-TS. The CoM postural sway was measured by the standard deviation of the CoM acceleration (Sadeh et al., 2023). The trunk, hip, knee, and ankle range of motion and range of angular velocity were computed by subtracting the maximum value of each parameter to its minimum, for each phase of Sit-TS and Stand-TS, defined ahead. The same computation was applied to the CoM position and velocity to calculate the CoM displacement and velocity range. Lower limb (hip, knee, and ankle) and trunk joint angles were measured in degrees and calculated as recommended by the ISB for the lower limb (Richards, 2018; Wu et al., 2002). The joint angular velocities of trunk, hip, knee, and ankle movements were computed in radians per second, describing the relative angular velocity of one segment relative to another segment (Richards, 2018). The COM was computed including all body segments considering the length of the body segments by the joint centers, and the position had as resolution coordinate system the laboratory coordinate system.

The Sit-TS and Stand-TS tasks were divided into 4 phases each, according previous literature on older adults movement analysis (Lin & Lee, 2022) and are described in detail on supplementary material (Appendix XVII). The Sit-TS was divided into flexion, momentum transfer, extension and stabilization, while the Stand-TS task was divided into initiation, flexion, momentum transfer and extension (Lin & Lee, 2022).

2.5 Data analysis

Data analysis was conducted using IBM SPSS Statistics for Macintosh, Version 29.0.2.0, (Armonk, NY: IBM Corp) with a significance level set at 0.05 for the statistical analysis. The normality of the distribution of the demographics, clinical characteristics, and disability indicators was evaluated using the Kolmogorov-Smirnov and Shapiro-Wilk tests for groups of older adults without and with disabilities, respectively. Between-group comparisons were assessed either with Mann-Whitney tests or independent sample t-tests, as appropriate. Chi-squared tests were employed to analyze associations between-group for categorical variables, specifically sex, history of falls, and SRH status.

The non-parametric Mann-Whitney U test was applied to compare older adults with and without functional disability time to complete the tasks, peak CoM acceleration/deceleration, and measures of anteroposterior (AP) and mediolateral (ML) postural sway.

PCA was conducted on the tridimensional lower limb joints and trunk range of motion, angular velocity ranges, and the CoM displacement and velocity ranges to construct distinct PCMs for each phase of Sit-TS and Stand-TS transitions. Potential outliers were manually inspected in the data and verified that one individual was an extreme outlier in parameters related to Stand-TS task, being fully excluded from Stand-TS PCMs.

A correlation matrix was used to ensure that each variable contributed equally to the analysis. The suitability of the dataset for PCA was determined using the Kaiser-Meyer-Olkin (KMO) as measure of sampling adequacy and Bartlett's Test of Sphericity, which assesses the appropriateness of data for dimensionality reduction. PCA was deemed suitable if Bartlett's Test yielded a statistically significant result ($p < 0.05$) and KMO values exceeded 0.5.

Principal components (PCs) were extracted for each PCM phase based on eigenvalues greater than 1, accounting for the majority of the variance. To enhance the interpretability of the components, a Varimax rotation was applied. The resulting rotated component matrix was analyzed to identify clusters of variables that loaded onto the same components, with emphasis placed on variables exhibiting high loadings (loading > 0.8) in accordance with (Hair et al., 1998)). Subsequently, a Sit-TS PCM was developed by aggregating these parameters with loadings exceeding 0.8 for each phase.

Finally, differences between older adults with and without disability across each of the kPCs of the Sit-TS PCM and Stand-TS PCM were assessed using the Mann-Whitney U test.

Ethics statement

The study adhered rigorously to the principles outlined in the Declaration of Helsinki. All participants received information about the study's purpose and methodology, and they completed an informed consent form. The study was submitted to the ESS, Polytechnic of Porto Institutional Ethics Committee on April 27, 2022, and obtained authorization on May 25, 2022 (Approval No CE0064C).

3. Results

A total of 62 participants out of 147 older adults initially participated in the study, as illustrated in Figure 1. However, two individuals exhibited symptoms that hindered their ability to complete the required tasks during the examination. Consequently, the final analysis incorporated data from 60 participants. The descriptive statistics summarizing their demographic and clinical characteristics are presented in Table 1.

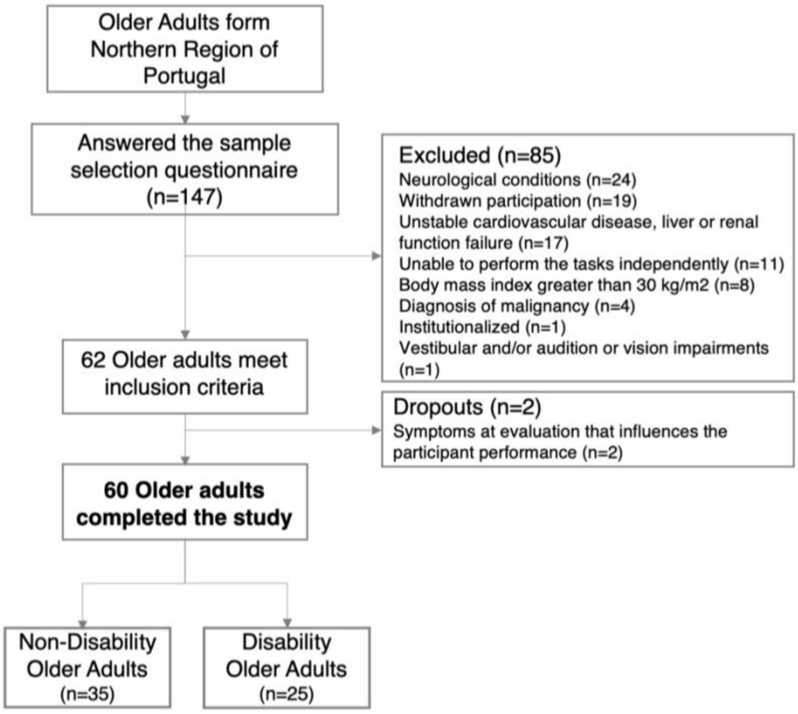


Figure 1:Flowchart illustrating the participant selection process.

No significant differences were observed in demographic or clinical characteristics between individuals with and without functional disability, except for polypharmacy. Older adults with functional disability demonstrated lower levels of independence in ADL and IADL (p=0.013 and p=0.002, respectively), reduced hand grip strength (p=0.018), and shorter duration in a one-leg stand posture (p<0.001). Additionally, compared to their non-disabled counterparts, individuals with functional disability reported poorer self-rated health (p<0.001).

Table 1:Demographic and clinical characterization of the sample. Data represented by the mean and standard deviation for ordinal variables, and frequencies for nominal variables. The p-value reflects the comparison between older adults without disability (ND) a and older adults with disability (D) by (a) Mann-Whitney U test, (b) Chi-square test, (c) Independent samples t-test.

		OA (n=60)	**ND** (n=35)	**D** (n=25)	***p*-value** (test value)
Demographic and clinical data					
Age (years)		67.86±6.46	66.34±5.60	68.60±6.77	0.147 (534)[(a)]
Gender (n female/ %)		38 (63.3)	19 (54.29)	19 (76)	0.085 (2.961)[(b)]
BMI (kg/m^2)		25.39±2.96	25.22±3.08	26.02±2.66	0.298 (-1.049)[(c)]
History of fall (n fallers/%)		22 (36.7)	11 (31.4)	11 (44)	0.469 (0.525)[(b)]
Polypharmacy (n polymedicated/%)		13 (21.7)	2 (5.71)	11 (44)	**<0.001** (12.595)[(b)]
Cognitive function (MMSE score)		28.74±1.38	28.94±1.31	28.68±1.49	0.495 (394)[(a)]
Self-reported physical activity (IPAQ MET-min/week)		3193.70±2829.86	3186.46±2964.91	3519..66±2822.11	0.509 (393.5)[(a)]
Disability indicators					
Self-Reported Health	*poor*	29 (48.3)	8 (22.86)	21 (84)	**<0.001** (21.832)[(b)]
	good	31 (51.6)	27 (77.14)	4 (16)	
Hand grip strength (Kg)		27.39±8.56	36.59±39.86	25.07±7.54	**0.018** (279.5)[(a)]
One Leg Standing time (seconds)		30.32±22.77	38.83±20.93	18.19±20.72	**<0.001** (192.5)[(a)]
ADL independence (Barthel Index score)		19.86±0.35	19.97±0.17	19.76±0.44	**0.013** (345)[(a)]
IADL independence (Lawton & Brody score)		22.70±1.23	23±0.00	21.96±2.67	**0.002** (332.5)[(a)]

The mean time required for older adults to complete the Sit-TS task was 2.57 seconds, while the Stand-TS task took 2.75 seconds. No significant differences were observed in task completion times or in the phases of these tasks between older adults with and without functional disability (Table 2). A significant difference was identified in peak AP CoM acceleration (p=0.015). Older adults with functional disability exhibited higher peak AP CoM acceleration compared to their non-disabled counterparts.

Table 2: Mean and standard deviation of overall Sit-TS and Stand-TS competition time and respective phases, peak center of mass (CoM) acceleration for Sit-TS and peak CoM deceleration for Stand-TS, anteroposterior (AP) and mediolateral (ML) postural sway of total sample (OA) and older adults without (ND) and with (D) disability. Differences between ND and D groups analyzed by Mann-Whitney test are represented by p-value (test value).

	OA (n=60)	ND (n=35)	D (n=25)	*p*-value (test-value)
Sit-ST time	2.57±0.69	2.59±0.74	2.55±0.62	0.940 (432.50)
Flexion time	0.7±0.17	0.72±0.16	0.66±0.18	0.239 (359.00)
Momentum transfer time	0.52±0.14	0.52±0.15	1.34±0.13	0.753 (416.50)
Extension time	1.19±0.58	1.19±0.60	1.18±0.56	0.952 (433.50)
Stabilization time	0.16±0.06	0.15±0.05	0.18±0.06	0.035 (297.00)
Stand-TS time	2.75±0.73	2.88±0.72	2.56±0.70	0.121 (334.00)
Initiation time	1.06±0.50	1.11±0.53	1.00±0.46	0.514 (394.00)
Flexion time	0.30±0.13	0.32±0.14	0.27±0.11	0.315 (370.50)
Momentum transfer time	0.17±0.08	0.17±0.07	0.18±0.09	0.304 (369.00)
Extension time	1.21±0.35	1.29±0.30	1.11±0.38	0.087 (323.50)
Peak AP CoM acceleration Sit-TS	1.25±0.48	1.10±0.33	1.47±0.57	**0.015*** (276.00)
Peak AP CoM deceleration Stand-TS	-0.91±0.71	-1.01±0.89	-0.77±0.27	0.393 (380.50)
AP postural sway Sit-TS	0.47±0.15	0.48±0.17	0.45±0.11	0.605 (403.00)
AP postural sway Stand-TS	0.36±0.11	0.36±0.13	0.35±0.10	0.934 (432.00)
ML postural sway Sit-TS	0.10±0.03	0.11±0.04	0.09±0.02	0.089 (324.00)
ML postural sway Stand-TS	0.12±0.04	0.12±0.04	0.12±0.04	0.840 (424.00)

The results of preliminary PCMs involving tridimensional lower limb joints and trunk range of motion, angular velocity ranges, and the CoM displacement and velocity range across the different phases of Sit-TS and Stand-TS are described in Tables S1 to S8 of the supplementary material (Appendix XVII).

For the Sit-TS phases, the four PCMs yielded KMO values ranging from 0.545 to 0.842, confirming the suitability of the study sample for dimensionality reduction. Bartlett's Test of Sphericity was also significant ($p<0.001$). The PCMs explained between 76.30% and 85.59% of the data variance, with the Stabilization PCM accounting for the highest percentage of total variance. The 34 kinematic parameters with loadings higher than 0.8

in each of the PCM were gathered to construct the PCM for Sit-TS task, as illustrated in figure 2. This model explained 81.85% of the total variance, with sample adequacy confirmed by a KMO value of 0.597 and a significant Bartlett's Test of Sphericity ($p<0,001$).

The first component accounted for 21.47% of the total variance and included kinematic parameters from the stabilization phase related to transverse hip and knee control. The second component encompassed frontal and transverse control of the trunk and hip during the flexion phase. The third component, explaining 11.36% of the total variance, primarily described the sagittal knee and ankle control in the momentum transfer and extension phases. The fourth component describes the ankle joint control during the flexion phase. The fifth and sixth components, although explaining 6.43% and 5.52% of the total variance, respectively, did not include parameters with loadings above 0.8, ensuring that the model prioritizes task-relevant kinematics. A similar pattern was observed for the eighth and ninth components. The seventh component described transverse hip and trunk angular velocity ranges during the flexion phase. None of the PCs scores revealed significant differences between older adults with and without functional disability.

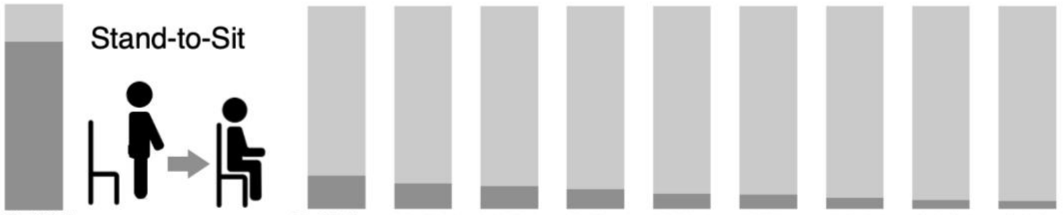
81.85%	21.47%	14.50%	11.36%	9.94%	6.43%	5.52%	4.45%	4.20%	3.98%
Transverse knee Δvelocity - Stabilization	**0.955**	0.089	0.123	0.099	0.047	-0.024	-0.015	-0.04	0.012
Transverse hip ROM - Stabilization	**0.955**	0.098	0.093	0.042	0.168	-0.032	0.007	0.019	-0.03
Transverse knee ROM - Stabilization	**0.954**	0.044	0.046	0.043	0.171	0	-0.032	0.014	-0.013
Transverse hip Δvelocity - Stabilization	**0.924**	0.056	0.199	0.118	0.083	0.005	0.013	-0.089	0.04
Frontal knee ROM - Stabilization	**0.921**	0.002	0.086	-0.044	0.191	-0.009	0.039	-0.009	-0.081
Frontal trunk ROM - Flexion	0.056	**0.94**	-0.007	0.02	0.04	0.046	0.093	0.033	0.108
Frontal hip Δvelocity - Flexion	0.189	**0.934**	0.033	0.038	0.004	-0.003	0.137	-0.003	0.023
Transverse hip ROM - Flexion	0.01	**0.905**	0.04	0.151	0.014	-0.013	0.121	0.06	0.114
Frontal trunk Δvelocity - Flexion	0.072	**0.898**	-0.071	-0.004	0.002	-0.018	0.122	-0.011	0.127
Sagittal knee Δvelocity - Extension	0.142	-0.095	**0.943**	0.107	0.085	0.037	-0.055	-0.051	-0.001
Sagittal ankle Δvelocity - Extension	0.188	-0.105	**0.924**	0.069	0.03	-0.035	-0.07	-0.039	0.049
Sagittal knee Δvelocity - MT	0.201	0.025	**0.877**	-0.097	0.225	0.103	0.071	-0.189	-0.073
Transverse ankle Δvelocity - Extension	0.086	0.107	**0.833**	0.21	-0.105	-0.015	-0.009	0.003	0.128
Vertical CoM Δvelocity - MT	-0.018	0.189	0.718	-0.017	0.168	0.44	0.068	0.096	-0.168
Sagittal knee ROM - Extension	-0.255	-0.114	0.395	-0.348	-0.15	0.37	0.073	-0.16	-0.064
Frontal ankle Δvelocity - Flexion	-0.073	-0.003	0.01	**0.922**	-0.097	0.056	-0.001	0.027	-0.016
Tranverse ankle ROM - Flexion	0.04	0.159	0.005	**0.902**	0.027	0.006	-0.059	0.026	-0.092
Sagittal ankle ROM - Flexion	0.099	-0.082	0.017	**0.860**	0.059	-0.013	0.236	-0.02	0.005
Transverse ankle Δvelocity - Flexion	0.165	0.139	0.306	**0.845**	-0.001	0.007	0.059	0.073	0.123
Vertical CoM displacement -Stabilization	0.339	0.106	0.084	0.015	0.793	0.26	0.034	0.037	0.011
Sagittal trunk ROM - Stabilization	0.366	-0.038	0.105	0.046	0.785	0.198	-0.067	-0.048	0.007
Sagittal knee Δvelocity - Stabilization	0.377	0.371	0.263	-0.027	0.504	-0.066	-0.144	-0.16	-0.059
Sagittal trunk Δvelocity - Extension	-0.183	-0.054	0.042	0.021	0.235	0.736	0.07	0.168	0.129
Transverse trunk Δvelocity- Stabilization	0.273	-0.047	0.165	-0.035	0.167	0.678	-0.135	-0.125	0.192
AP CoM displacement - Extension	-0.163	0.114	-0.037	0.073	-0.477	0.51	-0.172	0.359	-0.271
Vertical CoM Δvelocity - Flexion	-0.182	0.456	0.093	0.128	0.234	0.485	0.251	0.151	-0.353
Sagittal ankle ROM - MT	0.179	0.166	0.068	0.174	-0.424	0.485	0.039	-0.464	0.022
Transverse hip Δvelocity - Flexion	-0.074	0.216	0.103	0.078	-0.034	0.029	**0.890**	0.022	0.099
Transverse trunk Δvelocity - Flexion	0.083	0.251	-0.141	0.106	-0.010	-0.041	**0.866**	-0.03	0.082
ML CoM Δvelocity - Extension	-0.294	-0.057	-0.032	0.141	-0.133	-0.021	0.027	0.724	0.168
ML CoM displacement - Flexion	0.283	0.180	-0.163	0.075	0.074	0.175	0.022	0.709	-0.010
Frontal trunk ROM - MT	-0.08	0.453	-0.079	0.021	-0.006	0.04	0.04	0.133	0.682
Transverse trunk ROM - MT	-0.06	0.368	0.118	-0.179	-0.038	0.176	0.235	0.158	0.672
Sagittal trunk ROM - MT	-0.004	-0.093	0.001	0.318	0.194	0.05	0.097	-0.511	0.581
***p*-value** (test –value)	0.152 (342.00)	0.946 (433.00)	0.544 (397.00)	0.759 (417.00)	0.170 (346.00)	0.793 (420.00)	0.239 (359.00)	0.605 (403.00)	0.875 (427.00)

Figure 2: Principal component model of Sit-to-Stand task. Loadings above 0.8 are in bold and the p-values correspond to the differences between older adults with and without disability according Mann-Whitney U test. (MT-Momentum transfer phase; ROM – Range of motion; Δvelocity – range of angular velocity)

For the Stand-TS task, the outliers analysis identified one severe outlier across multiple kinematic parameters. All kinematic data for this participant were excluded from the model computation for the PCM across the four phases. The KMO values of these models ranged from 0.588 to 0.747, with Bartlett's Test of Sphericity yielding $p<0,001$. The total variance explained by each Stand-TS phase accounted ranged from 77.10% to 80.30%, with the initiation phase PCM accounting for the highest percentage. Following the same procedure as the Sit-TS PCM, 32 kinematic parameters with loadings higher than 0.8 in each PCM were gathered to construct the PCM for Stand-TS task.. However, four variables with communalities (representing the proportion of variance explained by the factors) lower than 0.650 were excluded to achieve a KMO value greater than 0.5, reflecting only variables that meaningfully contributed to the extracted components. The final Stand-TS PCM comprised 28 kinematic parameters explaining 81.59% of the total variance (Figure 3). The first component accounted for 16.65 of the total variance and included hip and knee frontal and transverse angular velocity during the flexion phase. The second component also comprised angular velocity data, specifically from the hip and trunk during the extension phase. The third component contained only one parameter with loading above 0.8, the vertical CoM angular velocity range during the extension phase. The fourth component did not included any parameters with loadings above 0.8. The fifth, sixth and seventh component each included two kinematic parameters related to the initiation and momentum transfer phases. The fifth and seventh component featured AP CoM velocity range, sagittal hip angular velocity range, and sagittal knee and ankle ROM during the initiation phase. The sixth component included sagittal knee ROM and vertical CoM displacement during the momentum transfer phase.

The eight component consisted solely of transverse ankle ROM during the extension phase, with loading above 0.8. The ninth component included sagittal and frontal trunk angular velocity ranges during the momentum transfer phase.

Comparison of principal components scores between older adults with and without functional disability revealed significant group differences in the fourth and ninth components.



81.59%	16.65%	13.05%	11.56%	9.99%	7.81%	7.37%	5.98%	4.84%	4.34%
Frontal hip Δvelocity - Flexion	**0.922**	-0.027	0.097	-0.126	0.178	-0.107	0.008	-0.023	-0.026
Transverse knee Δvelocity - Flexion	**0.908**	-0.024	0.09	-0.207	0.136	-0.111	-0.024	-0.052	-0.046
Frontal knee Δvelocity - Flexion	**0.812**	-0.043	0.123	0.104	-0.114	-0.230	0	0.088	0.110
Transverse knee Δvelocity - Initiation	0.633	0.091	-0.204	-0.206	0.115	-0.008	0.081	0.211	-0.113
Sagittal trunk Δvelocity - Extension	-0.044	**0.942**	-0.005	0.14	-0.083	-0.039	-0.024	-0.054	-0.027
Sagittal hip Δvelocity - Extension	-0.008	**0.915**	-0.235	0.171	0.075	-0.054	-0.059	-0.018	0.037
Frontal trunk Δvelocity - Extension	0.016	**0.914**	-0.086	0.025	0.035	-0.013	-0.071	-0.107	0.108
Vertical CoM Δvelocity - Extension	0.11	0.119	**-0.819**	0.282	0.193	0.16	0.168	0.135	-0.064
Frontal ankle ROM - MT	0.302	-0.186	0.761	0.202	-0.077	0.257	-0.084	0.153	0.06
Sagittal knee Δvelocity - Extension	0.156	0.106	-0.762	0.137	0.241	0.267	-0.084	0.3	-0.038
Frontal ankle Δvelocity - MT	0.422	-0.136	0.743	0.098	-0.002	0.071	0.065	0.267	0.067
Vertical CoM Δvelocity - MT	-0.147	0.186	0.520	-0.201	0.487	0.172	0.344	0.146	0.096
Transverse knee Δvelocity - MT	0.325	-0.043	0.108	-0.732	0.165	0.18	-0.113	0.178	-0.078
Frontal hip Δvelocity - MT	0.239	-0.006	0.045	-0.718	0.156	0.191	-0.186	0.065	0.271
Sagittal trunk ROM - Initiation	-0.199	0.113	-0.027	0.621	0.258	0.248	0.19	-0.027	-0.099
Sagittal ankle ROM - Flexion	0.07	0.272	-0.081	0.616	-0.239	0.082	-0.044	0.081	-0.08
Frontal ankle ROM - Flexion	0.126	0.204	0.165	0.445	-0.113	-0.312	-0.205	0.262	0.037
AP CoM Δvelocity - Initiation	0.049	0.04	-0.225	-0.222	**0.864**	-0.033	0.058	0.033	-0.062
Sagittal hip Δvelocity - Initiation	0.277	-0.055	-0.125	-0.036	**0.849**	-0.121	-0.05	0.079	-0.058
Sagittal knee ROM - MT	-0.17	-0.022	0.058	-0.021	-0.12	**0.924**	-0.037	-0.028	0.013
Vertical CoM displacement - MT	-0.194	-0.069	-0.077	-0.076	-0.014	**0.902**	0.227	0.032	-0.061
Sagittal knee ROM - Initiation	0.06	-0.092	-0.023	0.112	0.236	0.019	**0.863**	-0.151	-0.144
Sagittal ankle ROM - Initiation	0.066	-0.135	0.013	0.187	-0.159	0.124	**0.849**	-0.125	-0.129
Transverse ankle ROM - Extension	0.087	-0.128	-0.002	-0.109	-0.022	0.021	-0.099	**0.893**	-0.008
Frontal ankle Δvelocity - Extension	0.138	-0.152	0.036	0.173	0.372	-0.114	-0.224	0.744	-0.136
Transverse trunk Δvelocity Initiation	-0.185	0.196	-0.081	-0.359	-0.135	0.164	0.482	0.484	0.124
Sagittal trunk Δvelocity - MT	-0.030	0.046	0.052	-0.142	-0.084	0.03	-0.096	0.069	**0.934**
Frontal trunk Δvelocity - MT	-0.016	0.057	0.098	-0.054	-0.016	-0.085	-0.103	-0.135	**0.940**
p-value (test-value)	0.349 (364.00)	0.782 (407.00)	0.529 (384.00)	**0.033*** (286.00)	0.471 (378.00)	0.092 (315.00)	0.570 (388.00)	0.830 (411.00)	**0.046*** (295.00)

Figure 3: Principal component model of Stand-to-Sit task. Loadings above 0.8 are in bold and the p-values correspond to the differences between older adults with and without disability according Mann-Whitney U test. (MT-Momentum transfer phase; ROM – Range of motion; Δvelocity – range of angular velocity)

4. Discussion

The aim of this cross-sectional study was to examine the kinematics of Sit-TS and Stand-TS transitions among older adults and investigate differences in these domains between older adults with and without functional disability. To address this objective, a comparative analysis of task duration, CoM acceleration, and measures of AP and ML postural sway was first conducted. The analysis revealed significant group differences in peak AP CoM acceleration during Sit-TS, with older adults with functional disability exhibing higher values of acceleration compared to their non-disabled counterparts. This increased acceleration among older adults has also been observed in comparative analyses with healthy young adults, where older individuals demonstrated greater acceleration to propel the upper body over the base of support and to initiate seat-off. This adaptation likely reduces the lower extremity forces required to elevate the body (Fujimoto & Chou, 2012). According to the results of this study, the strategy appears to be more pronounced in older adults with functional disabilities.

To comprehensively address the aim of this study, PCMs were computed for tridimensional lower limb joints and trunk range of motion, angular velocity ranges, and the CoM displacement and velocity ranges across different phases of Sit-TS and Stand-TS tasks. These PCMs were then integrated to construct comprehensive models for each task.

The Sit-TS PCM explained 81.85% of the total variance, emphasizing the importance of parameters during the stabilization phase, particularly the role of transverse hip and knee control. The Sit-TS task poses a significant challenge as it involves transitioning from a large and stable base of support to a narrow and unstable one in the standing position (Sadeh et al., 2023). Early studies have underscored the need to further investigate stabilization following the attainment of an upright posture (Lindemann et al., 2007). A recent study suggested that the stabilization phase of Sit-TS is particularly challenging for functionally independent older adults compared to younger adults evidenced by analyses of center of pressure displacement (Piano et al., 2020).

The flexion phase also emerges as critical in older adults' performance of the Sit-TS task, as highlighted in principal components two, four and seven, which collectively accounted for 28.89% of the total variance. Although this phase is often characterized by the forward trunk transfer and maximum hip flexion (Norman-Gerum & McPhee, 2020), the PCA performed in this study emphasized the importance of frontal and transverse control of the trunk and hip. A recent systematic review reported increased trunk flexion in older adults compared to younger individuals and highlighted the need for comprehensive analyses of movements in the frontal and transverse planes. The joint functioning in these planes may be key factors in identifying age-related differences in balance regulation during the Sit-TS task (Sadeh et al., 2023). The importance of frontal hip control might be associated to the age-related weakening of the hip abductors, known to influence gait performance (Gordon et al., 2014), that may also impact Sit-TS performance during this phase in older adults. The third PC, reporting sagittal knee control during momentum transfer and extension and sagittal and transverse ankle velocity range at extension, reinforces the age-related compensations in relation to healthy adults of knee and ankle musculature (van der Kruk et al., 2021). Literature reports higher activation of rectus femoris, hamstrings, gastrocnemius and soleus in older adults compared to younger adults, possibly to compensate the reduced trunk flexion while standing up (van der Kruk et al., 2021).

The Sit-TS task is a bipodal movement characterized by significant kinematic changes in the sagittal plane, which has traditionally been the primary focus of research (Fotoohabadi et al., 2010; Sadeh et al., 2023). However, the present study PCA revealed that transverse and frontal plane control of the trunk, hip and knee joints play a significant role in the movement. Notably, the critical sagittal plane kinematics of the knee and ankle were retained in the third principal component (PC), indicating their contribution was not among the primary sources of variability. This finding suggests that the parameters contributing most to the components explaining the majority of variance are not necessarily the most relevant for achieving the task goal. In other words, individual variability in this task appears to be more associated with less critical parameters. This observation aligns with Uncontrolled Manifold (UCM) theory, which posits that the central nervous system organizes variability to ensure stability in task-relevant dimensions while allowing variability in other, less goal-related dimensions (Latash & Huang, 2015; Latash et al., 2010). According to the UCM theory, the central nervous system utilizes a manifold of solutions to achieve a motor task, allowing for flexibility and robustness in movement (Latash & Huang, 2015; Latash et al., 2010). The UCM theory has previously been applied to the study of Sit-TS task highlighting that the position of the CoM in the sagittal plane is tightly controlled, while the horizontal head position and the position of the hand were controlled less stably (Scholz et al., 2001; Scholz & Schöner, 1999). The present PCA emphasizes the key sagittal plane parameters required for the task goal. Meanwhile, similar to the head and hand positions, the transverse and frontal plane parameters, which contribute less to the task goal, are permitted greater variability. This reflects a prioritization of task-relevant stability over strict control of all movement dimensions.

The Stand-TS PCM presented similar total variance explained as the Sit-TS model, specifically 81.59%, with the first component gathering parameters of the flexion phase. The first PC, which accounted for the largest variance, included hip and knee frontal and transverse angular velocity during this phase. The second component consisted of sagittal hip and trunk angular velocity, while the third component included the vertical CoM angular velocity range, all measured during the extension phase. In contrast with the Sit-TS task, the PCA for its reverse function revealed that task-relevant kinematics were among those explaining the largest variance, primarily in the second and third components. Additionally, the fifth component (AP CoM angular velocity range and sagittal hip angular velocity range at initiation) and seventh component (sagittal knee and ankle ROM) also included task-relevant kinematics.

As for the flexion phase, the majority of the studies highlight the decrease of trunk flexion of older adults compared to younger ones (Dubost et al., 2005; Jeon et al., 2021). The decreased trunk flexion, combined with impaired eccentric control of knee extensors minimizes forward body displacement during sitting, has been linked to Stand-TS instability in aging. This is considered an adaptive mechanism to reduce the risk of anterior disequilibrium (Dubost et al., 2005; Jeon et al., 2021).

However, in this PCA analysis, sagittal trunk ROM during the flexion phase did not load higher than 0.8 on the flexion phase PCM, and thus excluded from Stand-TS PCM. Instead, sagittal and frontal trunk angular velocity range at momentum transfer were included in the model under the ninth PC. This finding suggests that beyond the well-documented reduction in sagittal trunk ROM (Jeon et al., 2021), trunk motion in the frontal plane warrants further investigation. In older adults with functional disability, these parameters differ significantly compared with older adults without disability. Studies on stroke patients often report increased lateral trunk flexion toward the nonparetic side (Onursal Kılınç et al., 2023). However, the role and significance of frontal plane trunk motion in older adults with functional disabilities remain to be thoroughly explored.

Comparisons of PC scores between disability groups suggest that the Stand-to-Sit (Stand-TS) task is more discriminative in distinguishing older adults with and without functional disabilities, as two PCs showed significant differences. This finding aligns with recent literature, which recommends incorporating Stand-TS training into comprehensive balance interventions (Jeon et al., 2021), despite the Sit-to-Stand (Sit-TS) task being more commonly assessed and rehabilitated (Duarte Wisnesky et al., 2020). Furthermore, the results of the PCMs for each task support the importance of evaluating the Stand-to-Sit (Stand-TS) task in older adults. While in the Sit-to-Stand (Sit-TS) task, the principal components include parameters that are less directly relevant to the task goal, in the Stand-TS task, the parameters explaining the greatest variance are more critical to achieving the task.

This study should be interpreted while acknowledging its limitations, particularly the sample size. To address this, rigorous measures were implemented to ensure sampling adequacy and the suitability of the data for dimensionality reduction across all models employed. Additionally, it is important to note that the tasks were performed without hand support and with foot placement determined by the participant. While standardization was ensured for the assessed sample, it is well established that the ability to perform a Sit-to-Stand (Sit-TS) movement is influenced by these and other factors, such as chair seat height and the use of armrests (Janssen et al., 2002). Altering these performance conditions could potentially change the domains identified through PCA.

Furthermore, this study incorporated factors not commonly considered in previous research on age-related impacts, such as the range of activity levels (Sadeh et al., 2023). Notably, this study confirmed that there were no differences in self-reported physical activity between the two groups of older adults, ensuring that differences observed are not confounded by variations in activity levels.

In summary, the kinematics of Sit-TS and Stand-TS transitions in older adults are explained through PCMs, each consisting of nine PCs, accounting for over eighty percent of the variance. The Sit-TS domains emphasize the role of transverse hip and knee joint control for achieving a stable upright position, the importance of hip abduction/adduction control during flexion phase, and higher knee and ankle control at momentum transfer and extension phases. The Stand-TS emerges as the most discriminative task in distinguishing older adults with and without functional disabilities, as significant differences were observed in PC4 and PC9. PC4 encompassed transverse knee and frontal hip kinematics, while PC9 represented sagittal and frontal trunk angular velocity ranges during momentum transfer.

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Declaration of interest statement

The authors report there are no competing interests to declare.

Data availability statement

The dataset generated and/or analyzed during the current study is not publicly available due to confidentiality of the data.

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Study VII - Principal component analysis of timed up and go kinematics in older adults: cross-sectional study comparing functional disability status

Submitted to a scientific journal

ABSTRACT

Purpose: To characterize older adults' kinematic performance during Timed up and go (TuG) and differentiate kinematic profiles of those with and without functional disability.
Methods: Cross-sectional study evaluating TuG performance in adults aged 60+ (n=60). Five Principal Component Models (PCMs) examined tri-dimensional lower limb, trunk ranges of motion (ROM), velocity, center of mass (CoM) displacement and velocity across TuG phases (sit-to-walk, walk forward, turn, walk back and turn-to sit). Variables with loadings >0.8 were retained for TuG PCM construction. Principal component (PC) scores were compared between disability groups.
Results: TuG PCM included 11 PCs, explaining 84.33% of variance. PCs included: sagittal hip, knee, CoM velocity during turn and walk phases (PC1); tri-dimensional trunk velocity at turn, walk back, and sit-to-walk (PC2, PC4, PC6); sagittal knee and hip velocity during sit-to-walk (PC3); frontal and transverse knee ROM and velocity during turn (PC5); vertical CoM displacement during turn (PC7) and mediolateral during turn and walk back (PC8); transverse ankle (PC9) and hip (PC10) ROM and velocity range during walk forward and walk back (PC11). PC1 and PC4 significantly differed between functional disability groups.
Conclusion: This study highlights key differences in sagittal hip kinematics and tri-dimensional trunk velocity in subjects with functional disability.

Keywords: Functional test; Factor analysis; Geriatrics, Biomechanics; Kinematics

1. Introduction

Timed Up and Go (TUG) has been described as a simple yet effective tool for assessing dynamic balance and functional mobility, requiring minimal equipment (Ortega-Bastidas et al., 2023). Originally developed by Podsiadlo and Richardson in 1991, the test measures, in seconds, the time it takes for an individual to complete a series of tasks: standing up from a standard chair, walking a distance of three meters, turning around, walking back to the chair, and sitting down again (Podsiadlo & Richardson, 1991). Over the past two decades, the TUG test has been widely used both in clinical settings and at home environments to evaluate functionality (Sprint et al., 2015). It serves as a reliable clinical tool for assessing functional mobility in healthy older adults (Herman et al., 2011). Furthermore, the time taken to complete the test has predictive value for identifying the risk of future disabilities in basic activities of daily living (ADLs) and instrumental activities of daily living (IADLs) among older adults who are initially free of disabilities (Donoghue et al., 2014). Additionally, disability-predictive cut-off values have been established for the TuG test (Choo et al., 2021). However, the kinematic performance of adults with 60 or more years during the TUG has been explored not by directly comparing older adults with and without disabilities but rather by contrasting their performance with that of younger adults (Kurosawa et al., 2020; van der Kruk et al., 2022), and predominantly older adults with Parkinson's disease (Ortega-Bastidas et al., 2023).

Compared to younger adults, older adults take significantly longer time to complete the turning and sitting subtasks, exhibit higher trajectories, decreased body inclination during the turn phase (Kurosawa et al., 2020), decreased ankle plantarflexion and hip flexion range of motion (ROM) (van der Kruk et al., 2022). Studies assessing older adults' performance during specific phases that are included in TuG (Bovonsunthonchai et al., 2015; Lin et al., 2014; Madrid et al., 2023; Perera et al., 2022; Thigpen et al., 2000) demonstrated that compared to younger adults, older adults do not use a pivot-shift strategy, instead they move more slowly, require more steps, take more time, exhibit shorter step length and longer step duration (Bovonsunthonchai et al., 2015; Thigpen et al., 2000) and have smaller spatial parameters, a longer double-support phase, and a higher stance-to-cycle ratio during turning gait manouvers (Madrid et al., 2023). The sit-to-walk task has also been comprehensively studied, with a systematic review identifying distinct strategies: forward continuation, balance, and sit-to-stand-to-walk transitions, each characterized by unique biomechanics (Perera et al., 2022). Few studies have investigated the walk and turn-to-sit kinematics, highlighting that older adults demonstrate lower displacement angles and velocities in the lumbar spine, head, and knee during various turning phases compared to younger adults. Additionally, the onset of lumbar movement and lateral head flexion occurs significantly earlier in older adults than in younger individuals during turning (Lin et al., 2014).

Given the strong evidence supporting the predictive value of TuG for disability (Choo et al., 2021; Donoghue et al., 2014), is essential to understand the parameters that influence performance, particularly those associated with lower completion values, by directly comparing older adults with and without functional disability.

Notably, there is a lack of studies that directly compare these groups, as well as limited number of investigations employing advanced technological systems (Ortega-Bastidas et al., 2023). A systematic review examining technological approaches to segmenting and analyzing instrumented TUG performance in older adults with or without pathologies identified only two studies utilizing opto-electronic systems. One study focused on patients before and after total hip arthroplasty (Gasparutto et al., 2021), while the other examined patients with Parkinson´s disease (Van Uem et al., 2016).

The literature also highlights inconsistencies in the definition of TUG sub-phases.While some studies propose three sub-phases, such as sit-to-stand, walk, and stand-to-sit, others suggest more detailed segmentations with up to six sub-phases, including forward gait, 180° turn, and stand-to-sit (Ortega-Bastidas et al., 2023). This variability in defining transitions, such as sit-to-walk and turn phases, complicates comparisons across studies.

Given the scarcity of research employing gold-standard technology to assess older adults' TUG performance and the tendency of prior studies to focus on comparisons with younger adults or individuals with Parkinson’s disease, this study aims to characterize the older adults kinematic performance during TuG test and differentiate the kinematic profiles of older adults with and without functional disability. Specifically, the three-dimensional ROM of lower limb joints and the trunk, angular velocity, and the displacement and velocity of the center of mass (CoM) during sit-to-walk, walking forward, turn, walking back, and turn-to-sit subphases of TUG were considered for analysis. For the determination of kinematic profiles, the principal component analysis

(PCA) was performed on the parameters for each phase. The variables with significant variance (loading > 0.8) were selected to develop a principal component model (PCM) of TuG performance in older adults which were then compared between older adults with and without functional disability.

2. Material and Methods

2.1 Study design and participants

This cross-sectional study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Elm et al., 2008), and its protocol was registered in the ClinicalTrials.gov database (registration identifier: NCT05611723). The study was conducted at the Center for Rehabilitation Research, School of Health, Polytechnic of Porto.

A sample selection questionnaire was distributed across partner institutions of the research center between June 1, 2022, and March 31, 2023. Older adults who met all inclusion and exclusion criteria and voluntarily agreed to participate were contacted, and their assessments were scheduled. Data collection was carried out in the movement laboratory of the research center from June 1, 2022, to April 30, 2023.

The inclusion criteria included being aged 60 years or over, living in the community, and able to perform the tasks (gait, sit-to-stand, stairs negotiation) independently. Volunteers were excluded if they were institutionalized; had established diagnosis of malignancy or terminal diseases with an anticipated survival of less than 1 year; had stroke history, cerebral hemorrhage, head trauma, or Parkinson’s disease; had cognitive impairment, specifically Mini Mental State Examination (Portuguese version) score of 22 for 0 to 2 years of literacy, 24 for 3 to 6 years of literacy and 27 for more than 6 years of literacy (Morgado et al., 2009); had rheumatic pathologies that interfere with the tasks performance; had diabetic foot, lower limb fracture less than 6 weeks, or other related conditions; had unstable cardiovascular disease, liver or renal function failure; had a body mass index greater than 30 kg/m2; had vestibular and/or audition or vision impairments non corrected that influence the performance of tasks; or had the presence of symptoms at the time of evaluation that influences the participant performance of tasks.

2.2 Sample characterization

A questionnaire was used to collect information about participants' demographics, health conditions, and history of falls in the previous 12 months. Additional assessments included anthropometric measurements (height, weight, and body mass index), cognitive function (using the Mini-Mental State Examination), self-reported medication use, and self-reported physical activity levels (measured with the seven-item Portuguese version of the International Physical Activity Questionnaire: Short Form [IPAQ-SF]).

Body mass (in kilograms) was measured using a bioimpedance analyzer (Tanita Inner Scan BC-601) with a precision of 0.1 kg. Height was recorded using the seca® 222 stadiometer (seca—Medical Scales and Measuring Systems®, Birmingham, UK) with 1 mm accuracy. Cognitive function was evaluated using the Mini-Mental State Examination (MMSE) (Morgado et al., 2009) which has a total score range of 0 to 30. Medication use was self-reported, and polypharmacy was defined as the use of five or more prescription medications (E. A. Lee et al., 2020). Physical activity was assessed using the seven-item short version of the IPAQ-SF (Craig et al., 2003).

2.3 Disability status characterization and assessment

Participants were divided into two groups: older adults without disability and those with two or more disability indicators of the previously identified in the literature (Moreira et al., 2022). These indicators included handgrip strength (hand-held dynamometer), balance (single leg balance test time), overall self-reported health status (Self-reported question), basic activities of daily living (ADL) (Barthel Index) and instrumental ADL (IADL) (Lawton and Brody).

Handgrip strength was measured using the Jamar® Plus+ Digital handheld dynamometer (Performance Health Supply, Cedarburg, WI, USA). Participants were seated with the shoulder adducted, the elbow flexed at 90 degrees and unsupported, the forearm neutral, and the wrist extended at 30 degrees, following guidelines of the American Society of Hand Therapists (Jansen et al., 2008).

Balance was assessed using the one-leg stance test (OLST), where the total standing time on the participant's preferred leg, with eyes open, was recorded in seconds. The test ended when participants could no longer maintain the position or reached the maximum duration of 60 seconds. Imbalance was noted when the lifted leg touched the ground or the participant lost balance (Furuna et al., 1998).

Overall self-reported health status (SRH) was determined by the question, "In general, how do you rate your health today?" Responses were categorized as "very bad," "bad," "fair," "good," or "very good." For analysis, SRH was dichotomized into "good" (including "very good" and "good") and "poor" (including "fair," "bad," and "very bad") (Crimmins, 2004).

The Barthel Index (Araújo et al., 2007; Mahoney & DW, 1965) was used to evaluate independence in basic ADLs, with scores ranging from 0 (complete dependence) to 20 (functional independence) (Collin et al., 1988).

To assess functional capacity in instrumental ADLs, the Lawton and Brody Instrumental Activities of Daily Living Scale was used (Araújo et al., 2008; Lawton & Brody, 1969).

2.4 Kinematic Assessment

The TuG test performance was recorded using the Qualisys Track Manager (Qualisys AB®, Sweden), with eleven optoelectronic cameras (eight Oquos500, three MiqusM3), one Miqus video camera (Qualisys AB®, Sweden), and two force plates (FP4060-08/10, Bertec®). Kinematic data was collected at a 100Hz frequency. The researcher first verbally explained the test procedure and how to perform the task. Participants were asked to stand up from a standard chair (seat height 46 cm), walk at a comfortable pace to a line on the floor three meters away, turn around, walk back and sit down. Participants started with their backs to the chair and were instructed not to use their arms to stand up. Participants completed the TuG course once, before being timed, to familiarize themselves with the performance (Pisciottano et al., 2014; Podsiadlo & Richardson, 1991). Three valid trials were recorded.

2.5 Data processing and Kinematic parameters

The marker trajectories for each participant's three trials were processed using Qualisys Track Manager software (Qualisys AB®, Sweden 2020.3). The processed data was then exported to Visual3D Professional™ (C-Motion, Inc., EUA), which generated a full-body biomechanical model. This model, adapted from the collaboration between the Instituto

Ortopedico Rizzoli and other authors (Leardini et al., 2011), adding the head segment and Rab Upper Extremity Model (Petuskey et al., 2007).

The TuG was divided into five phases: sit to walk, walking forward, turning, walk back and turn to sit (Ansai et al., 2019; Gasparutto et al., 2021) (figure 1). The sit-to-walk initiation (T0) was defined as the instant of the first change in the vertical ground reaction force (value equal or lower than the mean minus 2 standard deviations of the baseline) (Kerr et al., 2004). The end of this transition (T1) was defined as the moment of the heel-off of swing limb corresponding to the maximum anteroposterior linear velocity of heel marker (Buckley et al., 2009). The walk forward initiated at T1 and ended when CoM mediolateral velocity crossed the zero value (T2). The start (T2) and end (T3) of the turn phase were defined as the instants when the CoM velocity inverted the signal and the participant reached a distance of 0.7 meters from the target, respectively (Kurosawa et al., 2020). The walk back phase started at the end of turn (T3) and ended when the left and right shoulder marker mediolateral velocity equalized (T4). The turn-to-sit phase started at T4 and ended before sitting, at first deflection of vertical GRF (value equal or lower than the mean minus 2 standard deviations of the baseline) as it is difficult to distinguish between the conclusion of the turn and the beginning of the sitting phase (Gasparutto et al., 2021).

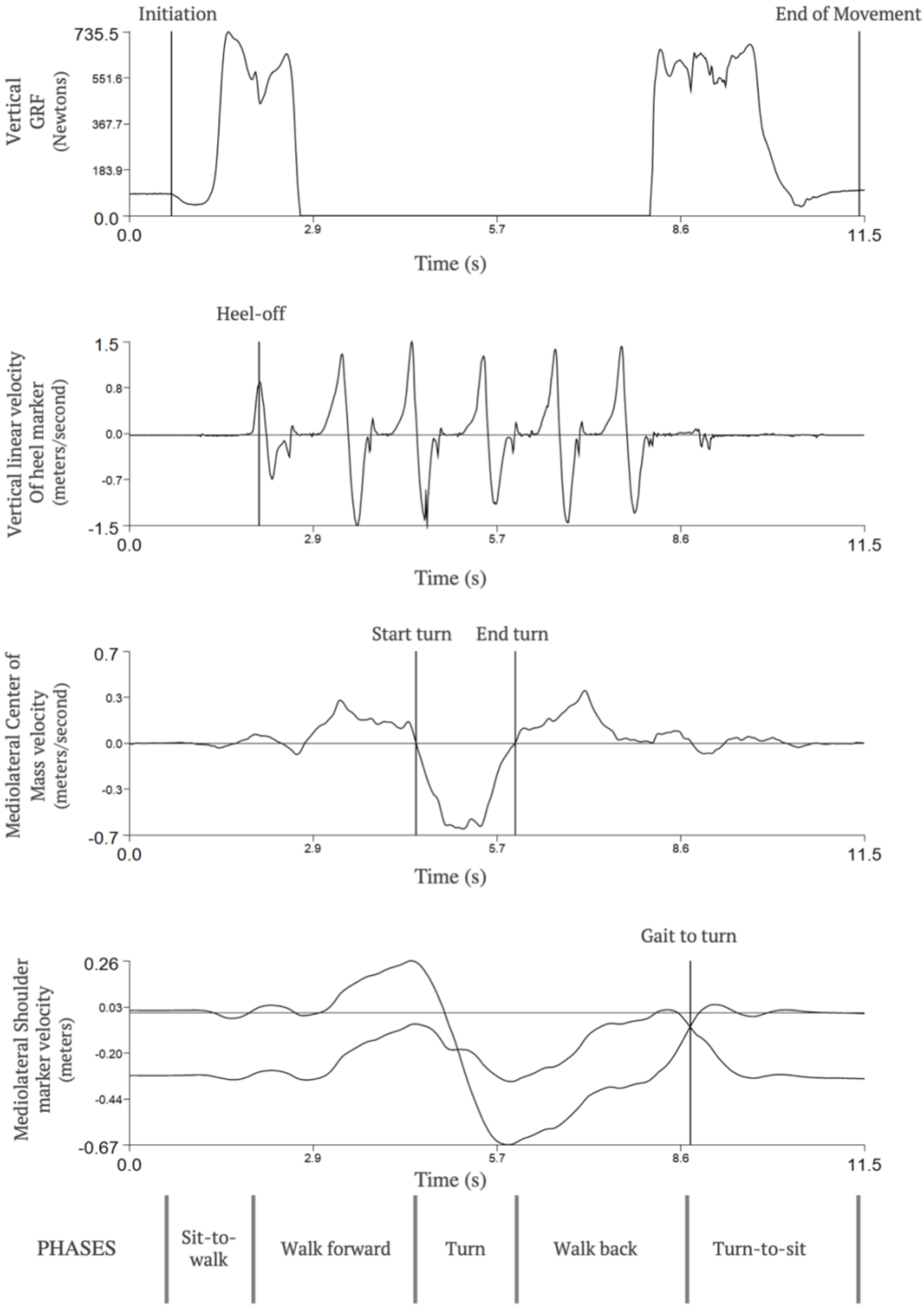

Figure 1: Timed up and go phases and respective events definition according to vertical Ground Reaction Force (GRF), vertical linear velocity of heel marker, mediolateral center of mass velocity and mediolateral shoulder marker velocity.

To characterize the TuG performance, the values from task and subphases completion time (seconds) were computed. For all phases of TuG the trunk, hip, knee, and ankle ROM and range of angular velocity were computed. These measures were obtained by subtracting the maximum value of each parameter to its minimum. The same computation was applied to the CoM position and velocity to calculate the CoM displacement and CoM velocity range. Lower limb and trunk joint angles were measured in degrees and calculated as recommended by the ISB for the lower limb (Richards, 2018; Wu et al., 2002). The joint angular velocities of trunk, hip, knee, and ankle movements were computed in degrees per second, describing the relative angular velocity of one segment relative to another segment (Richards, 2018). The COM was computed including all body segments considering the length of the body segments by the joint centers, and the position had as resolution coordinate system the laboratory coordinate system.

2.5 Data analysis

IBM SPSS Statistics for Mac OS, Version 29.0.2.0, was used to analyze the data, and a significance threshold of 0.05 was used for the analysis of statistics. The Shapiro-Wilk and Kolmogorov-Smirnov tests were used to assess the normality of the distribution of the disability indicators, clinical characteristics, and demographics for groups of older adults with and without disabilities, respectively. Independent sample t-tests or Mann-Whitney tests were used, where applicable, to evaluate between-group comparisons. To examine group relationships for categorical variables, specifically, sex, fall history, and SRH status, chi-squared tests were utilized.

PCA was conducted on the tridimensional lower limb joints and trunk ROM, angular velocity ranges, and the CoM displacement and velocity ranges to construct distinct PCMs for each phase of TuG. Potential outliers were manually inspected in the data and it was verified that two individuals were extreme outliers in several parameters of different TuG phases (one individual were more than 3 times the interquartile range above the third quartile at seven parameter at sit-to-walk, one parameter at turn and the other individual at three parameters in sit-to-walk, one at walk forward and four at walk back), being fully excluded from PCMs.

To ensure that each variable contributed equally to the analysis, a correlation matrix was employed. The dataset's suitability for Principal Component Analysis (PCA) was evaluated using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett’s Test of Sphericity, which assesses the data's appropriateness for dimensionality reduction. PCA was considered appropriate if Bartlett's Test produced a statistically significant result ($p < 0.05$) and KMO values exceeded 0.5.

Principal components (PCs) were extracted for each PCM phase based on eigenvalues greater than 1, capturing the majority of the variance. To improve the interpretability of these components, a Varimax rotation was applied (Jolliffe & Cadima, 2016). The rotated component matrix was then analyzed to identify clusters of variables that loaded onto the same components, with a focus on variables showing high loadings (loading > 0.8), as recommended by Hair et al. (1998) (Hair et al., 1998). A TuG PCM was subsequently developed by aggregating the parameters with loadings exceeding 0.8 for each phase.

Finally, the Mann-Whitney U test was used to assess differences between older adults with and without disabilities across each of the key principal components of the TuG PCM.

2.6 Ethical considerations

All participants were provided with detailed information about the study's purpose and methodology and signed an informed consent form, ensuring adherence to the principles of the Declaration of Helsinki (Association, 2013). The study was submitted to the Institutional Ethics Committee on April 27, 2022, and received approval on May 25, 2022 (Registration Number: CE0064C). Confidentiality was ensured by assigning a unique code to each participant's data, which was securely stored on a password-protected computer accessible only to the investigator.

3. Results

The study initially enrolled 147 older adults, with 62 participants actively taking part, as illustrated in figure 2. However, symptoms in two individuals impeded their ability to complete the required tasks during the examination. Consequently, the final analysis included data from 60 participants. Descriptive statistics summarizing their demographic and clinical characteristics are presented in table 1.

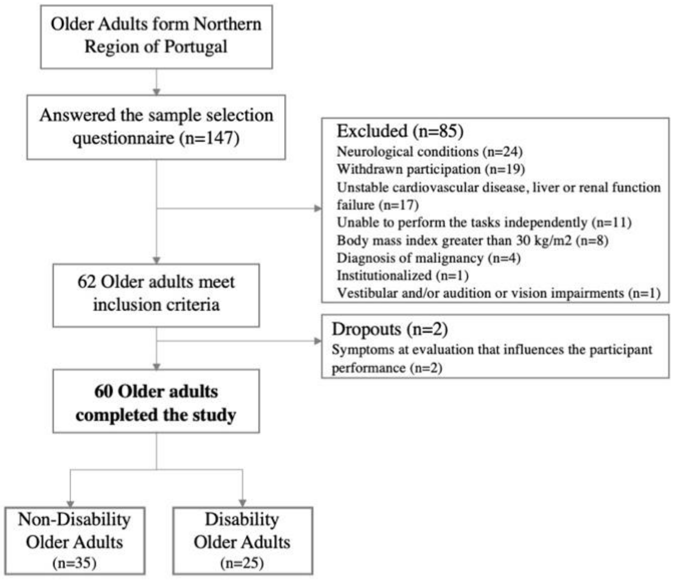

Figure 2: Flowchart illustrating the participant selection process.

The older adult participants had an average age of 67.86 years. Functional disability was associated with several differences, including reduced independence in ADL and IADL activities (p=0.013 and p=0.002, respectively), decreased hand grip strength (p=0.018), shorter one-leg stand durations (p<0.001), and poorer self-rated health (p<0.001). Other demographic and clinical characteristics showed no substantial differences between the two groups, except for polypharmacy.

Table 1: Demographic and clinical characterization of the sample. Data represented by the mean and standard deviation for ordinal variables, and frequencies for nominal variables. The p-value reflects the comparison between older adults without disability (ND)) and older adults with disability (D) by (a) Mann-Whitney U test, (b) Chi-square test, (c) Independent samples t-test.

	OA (n=60)	**ND** (n=35)	**D** (n=25)	***p*-value** (test value)
Demographic and clinical data				
Age (years)	67.86±6.46	66.34±5.60	68.60±6.77	0.147 (534)(a)
Gender (n female/ %)	38 (63.3)	19 (54.29)	19 (76)	0.085 (2.961)(b)
BMI (kg/m^2)	25.39±2.96	25.22±3.08	26.02±2.66	0.298 (-1.049)(c)
History of fall (n fallers/%)	22 (36.7)	11 (31.4)	11 (44)	0.469 (0.525)(b)
Polypharmacy (n polymedicated/%)	13 (21.7)	2 (5.71)	11 (44)	**<0.001** (12.595)(b)
Cognitive function	28.74±1.38	28.94±1.31	28.68±1.49	0.495

(MMSE score)					(394)[(a)]
Self-reported physical activity (IPAQ MET-min/week)		3193.70±2829.86	3186.46±2964.91	3519..66±2822.11	0.509 (393.5)[(a)]
Disability indicators					
Self-Reported Health	*poor*	29 (48.3)	8 (22.86)	21 (84)	**<0.001** (21.832)[(b)]
	good	31 (51.6)	27 (77.14)	4 (16)	
Hand grip strength (Kg)		27.39±8.56	36.59±39.86	25.07±7.54	**0.018** (279.5)[(a)]
One Leg Standing time (seconds)		30.32±22.77	38.83±20.93	18.19±20.72	**<0.001** (192.5)[(a)]
ADL independence (Barthel Index score)		19.86±0.35	19.97±0.17	19.76±0.44	**0.013** (345)[(a)]
IADL independence (Lawton & Brody score)		22.70±1.23	23±0.00	21.96±2.67	**0.002** (332.5)[(a)]

The older adults took approximately 11 seconds to complete the TuG test, with older adults experiencing functional disability requiring significantly more time than their counterparts. Each phase of the TuG was also significantly prolonged in the functional disability group, except for the turn and turn-to-sit phases, which did not show a statistically significant difference.

Table 2: Mean and standard deviation of overall TuG completion time and respective phases of total sample (OA) and older adults without (ND) and with (D) disability. Differences between ND and D groups analyzed by a Mann-Whitney U test or by b Independent sample t test are represented by p-value (test value).

Time		OA (n=60)	ND (n=35)	D (n=25)	*p*-value (test-value)
TuG		10.83±2.02	10.34±2.14	11.51±1.63	**0.006** (254.00)[a]
	Sit-to-walk	1.36±0.25	1.30±0.27	1.44±0.20	**0.015** (-2.21)[b]
	Walk forward	2.21±0.48	2.08±0.49	2.39±0.41	**0.003** (237.00)[a]
	Turn	1.78±0.32	1.71±0.29	1.87±0.35	0.086 (323.00)[a]
	Walk back	2.73±0.71	2.56±0.77	2.97±0.55	**0.007** (259.00)[a]
	Turn-to-sit	2.72±0.70	2.64±0.76	2.84±0.59	0.06 (312.00)[a]

Tables S1 to S5 in the supplementary material (Appendix XVIII) present the results of the preliminary PCMs, which assess the three-dimensional ROM and angular velocity of lower limb joints and the trunk, along with the displacement and velocity of the center of mass (CoM) across various TuG phases. The five PCMs produced KMO values ranging from 0.556 to 0.754, confirming the study sample's suitability for dimensionality reduction. Additionally, Bartlett's Test of Sphericity was significant ($p<0.001$), reinforcing the appropriateness of factor analysis. The PCMs explained between 76.44% and 82.08% of the total data variance, with the Walk Forward PCM accounting for the highest percentage. Across the different TuG phase PCMs, 59 variables exhibited factor loadings above 0.8. However, to maintain a KMO value above 0.5, 21 variables with communalities below 0.800—indicating a lower proportion of variance explained by the factors—were excluded, ensuring the retention of only variables with meaningful contributions to the extracted components. The PC1 primarily included variables from hip, knee and CoM velocity during walk back, walk forward and turn phases, explaining 22.21% of the total variance (table 3 and figure 3). PC2 encompassed tri-dimensional trunk velocity at turn phase, as well as PC4 in the walk back phase and PC6 in the sit-to-walk phase. PC3 included sagittal knee and hip velocity during sit-to-walk phase. PC5 included transverse knee ROM and velocity range along with frontal knee ROM during the turn phase. PC7 included only vertical CoM displacement during the turn phase, while PC8 included mediolateral CoM displacement during the turn and walk back phases. PC9 and 10 included variables from walk forward phase in the transverse plane, particularly ankle and hip ROM and velocity range, respectively. Additionally, transverse hip ROM and velocity range also loaded onto PC11 but were associated with the walk back phase. The PC1 and PC4 scores differed between older adults with and without functional disability, according to the PC score analysis (table 3 and figure 3).

Table 3: Principal component model of Timed up and go task. Loadings above 0.8 are in bold and the p-values correspond to the differences between older adults with and without disability according Mann-Whitney U test. (CoM – Center of Mass; ROM – Range of motion).

Principal component	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Explained variance (%)	22.21	11.31	9.18	7.34	6.57	5.86	5.45	4.98	4.31	3.70	3.42
Sagittal hip ROM Walk back	**0.877**	0.062	0.015	0.036	0.079	-0.036	-0.215	-0.018	-0.054	0.161	-0.041
Sagittal hip velocity range Walk back	**0.865**	0.049	-0.113	0.179	0.154	-0.03	-0.259	0.118	0.114	0.089	0.091
Vertical CoM velocity range Walk back	**0.864**	0.043	0.094	0.056	0.056	-0.067	0.174	0.057	0.189	-0.079	0.066
Sagittal hip ROM Walk forward	**0.855**	0.034	-0.266	-0.017	0.045	-0.004	0.008	0.117	-0.041	0.08	0.057
Sagittal knee velocity range Walk forward	**0.826**	-0.007	-0.159	0.074	0.116	0.066	0.055	0.134	0.133	0.004	0.035
AP CoM velocity range Turn	**0.816**	0.027	-0.175	-0.039	0.04	-0.153	0.188	0.198	0.154	0.094	0.11
Vertical CoM velocity range Turn	**0.812**	0.05	-0.099	0.052	0.006	-0.112	0.224	0.046	0.186	-0.156	0.085
Vertical CoM velocity range Walk forward	0.747	-0.061	-0.236	0.008	0.058	-0.045	0.524	0.002	0.072	0.041	0.093
ML CoM velocity range Walk forward	0.451	0.302	0.076	-0.071	-0.189	0.108	0.008	0.442	0.073	0.247	0.024
Frontal trunk velocity range Turn	-0.063	**0.950**	0.022	0.043	-0.056	0.081	-0.023	-0.013	-0.008	0.01	0.02
Sagittal trunk velocity range Turn	-0.08	**0.933**	-0.036	0.099	0.075	0.177	-0.056	-0.037	0.006	0.025	0.074
Frontal trunk ROM Turn	0.157	**0.833**	0.063	-0.013	-0.121	0.034	0.182	0.017	-0.096	-0.021	-0.015
Frontal hip velocity range Turn	0.205	0.785	-0.035	0.091	0.371	0.19	-0.059	0.037	0.009	0.0	0.08
Sagittal knee velocity range Sit-to-walk	-0.075	0.019	**0.892**	0.078	-0.017	0.018	-0.04	-0.045	0.094	0.139	0.016
Sagittal hip ROM Sit-to-walk	-0.218	-0.026	**0.852**	0.065	0.164	0.144	0.068	-0.018	-0.033	-0.127	0.03
Sagittal knee ROM Sit-to-walk	-0.506	0.109	0.738	0.11	-0.103	0.01	0.193	-0.067	-0.06	0.084	-0.038
Sagittal trunk velocity range Walk back	-0.094	0.075	0.151	**0.917**	0.077	-0.048	-0.043	-0.118	-0.063	-0.131	-0.031
Frontal trunk velocity range Walk back	0.014	0.067	0.161	**0.904**	-0.021	-0.08	0.057	0.095	-0.076	-0.039	0.032
Transverse trunk velocity range Walk back	0.307	-0.038	-0.038	**0.816**	0.044	-0.162	-0.032	-0.076	0.087	0.021	-0.089
Frontal trunk velocity range Walk forward	0.134	0.315	-0.284	0.475	0.200	0.243	-0.044	0.069	0.235	0.257	-0.108
Sagittal trunk velocity range Walk forward	0.04	0.277	-0.443	0.416	0.292	0.297	0.044	-0.078	0.32	0.171	-0.06
Transverse knee velocity range Turn	0.188	-0.014	-0.008	0.059	**0.904**	-0.05	0.013	0.132	-0.044	-0.03	0.115
Transverse knee ROM Turn	0.102	-0.074	0.132	0.049	**0.853**	-0.079	-0.044	0.004	-0.093	0.122	-0.147
Frontal knee ROM Turn	0.045	0.195	-0.047	0.041	**0.819**	-0.166	-0.098	0.014	0.08	0.162	0.016

Sagittal trunk velocity range Sit-to-walk	-0.102	0.047	0.05	-0.101	-0.113	**0.873**	0.116	-0.019	0.084	0.02	0.113
Frontal trunk velocity range Sit-to-walk	0.023	0.165	0.06	-0.042	-0.111	**0.846**	-0.167	0.043	-0.073	0.04	-0.068
Transverse trunk velocity range Sit-to-walk	-0.131	0.211	0.017	-0.056	-0.048	**0.814**	-0.056	0.077	-0.002	-0.124	0.115
Vertical CoM displacement Turn-to-sit	-0.038	0.091	0.154	0.038	-0.09	-0.12	**0.878**	0.015	-0.135	-0.083	0.053
Vertical CoM velocity range Sit-to-walk	0.564	-0.042	0.145	0.002	0.053	0.073	0.739	-0.025	0.012	0.045	-0.002
Sagittal trunk ROM Walk forward	0.084	-0.013	-0.504	-0.127	-0.167	-0.022	0.624	0.119	0.138	0.21	-0.078
ML CoM displacement Turn	0.216	0.068	-0.035	-0.105	0.086	0.03	-0.024	**0.932**	0.103	-0.024	-0.008
ML CoM displacement Walk back	0.146	-0.119	-0.092	0.047	0.097	0.04	0.068	**0.899**	0.013	-0.059	-0.054
Transverse ankle velocity range Walk forward	0.215	-0.101	0.001	-0.009	0.087	-0.023	0.007	-0.002	**0.918**	0.085	-0.02
Transverse ankle ROM Walk forward	0.255	0.014	-0.005	0.002	-0.181	0.032	-0.073	0.150	**0.883**	0.036	-0.005
Transverse hip ROM Walk forward	-0.012	0.048	0.021	-0.004	0.071	0.015	0.001	-0.067	-0.03	**0.911**	0.076
Transverse hip velocity range Walk forward	0.137	-0.04	-0.01	-0.074	0.16	-0.077	0.027	0.032	0.16	**0.887**	0.071
Transverse hip ROM Walk back	0.077	0.054	0.003	0.008	-0.129	0.129	-0.058	-0.065	-0.086	0.076	**0.882**
Transverse hip velocity range Walk back	0.230	0.061	0.048	-0.113	0.131	0.012	0.100	0.013	0.064	0.073	**0.875**
p-value (test-value)	**0.035** (278)	0.094 (306)	0.146 (320)	**0.035** (278)	0.832 (399)	0.282 (344)	0.061 (293)	0.206 (332)	0.179 (327)	0.783 (395)	0.906 (405)

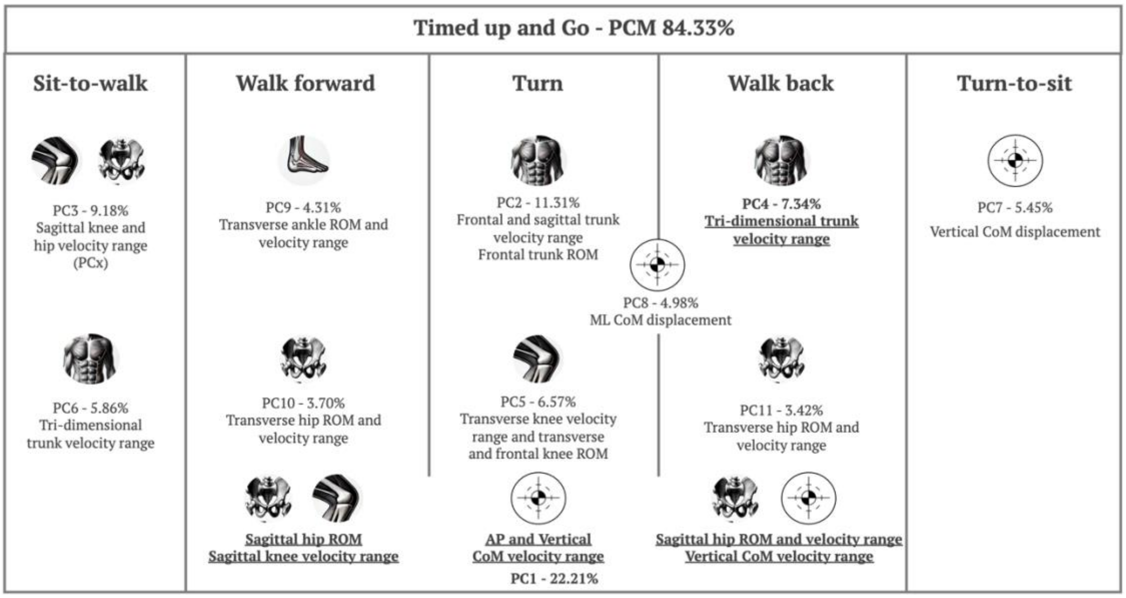

Figure 3: Principal Component Analysis descriptive diagram. Parameters with differences between older adults with and without functional disability are in bold.

4. Discussion

This cross-sectional study aimed to characterize the kinematic performance of older adults during the TuG test and to differentiate the kinematic profiles of those with and without functional disability. To achieve this, a comparative time analysis and a principal component analysis were conducted.

On average, older adults with functional disability required one additional second to complete the TUG test compared to those without disability. Both groups exceeded the 10 second threshold, a previously identified cut-off for functional dependency (J. E. Lee et al., 2020). Given that multiple cut-off values have been proposed in literature to predict functional disability (Choo et al., 2021; Donoghue et al., 2014), a more detailed analysis of the task is warranted. Accordingly, each phase of the TuG test was timed, revealing that the functional disability group took significantly longer in sit-to-walk, walk forward and walk back phases. Although increases in time were also observed in the turn and turn-to-sit, these differences were not statistically significant. Previous studies have reported phases that older adults require increased time ratio to complete turning and sitting subtasks compared to younger adults, with older individuals exhibiting an extended turn trajectory (Kurosawa et al., 2020). It has also been documented that older adults employ a compensatory and conservative strategy, the sit-to-stand-and-walk, in which they reach an upright position and briefly pause before initiating gait (Perera et al., 2022). The findings of the present study suggest that this stability-prioritizing strategy may be further exacerbated in older adults with functional disability. Additionally, prolonged time in the walk forward and walk back phases align with findings from studies on frail versus non-frail older adults, where reduced gait speed was associated with increased phase durations (Ansai et al., 2019). This slower gait speed is also characteristic of older adults with functional disability (Abe et al., 2019; Doi et al., 2020; Perera et al., 2016).

The PCA analyzed the three-dimensional ROM of lower limb joints and the trunk, angular velocity ranges, and the displacement and velocity ranges of CoM, for each of the five TuG test phases. From an initial set of 150 variables, the PCMs filtered those with factor loadings above 0.8, retaining 59 variables. However, 21 of these variables exhibited low communalities and were excluded, a crucial step to ensure that only variables with meaningful contributions were retained, resulting in KMO value above 0.5. The assessment of sample adequacy and data suitability for reduction is critical for PCA, yet it remains under reported in biomechanics and related fields (Rojas-Valverde et al., 2020). A PCM of the TuG task was computed for the 38 retained variables, yielding 11 PCs that collectively explained 84.33% of the total variance. The phases contributing most to variance were turn, walk back and walk forward phases. Prior research has reported a significant decrease in step length, an increase in step time, and a reduction in step speed during the turn phase (Bovonsunthonchai et al., 2015). These variations may be reflected in the variance of AP CoM velocity range of turn phase, which loaded onto the first PC. Furthermore, a correlation has been established between walking phases and the contraction and delay time of the vastus medialis muscle (Ziegl et al., 2021), which, in this study, is highlighted by the sagittal knee velocity range also loading onto PC1. Additionally, increased biceps femoris muscle stiffness, has shown significant correlations with walk-forward and walk-back times (Ziegl et al., 2021). This relationship may be represented in the PCM, where sagittal hip ROM in the walk forward and walk back phases, along with velocity range in the latter phase, loaded onto PC1. Transverse hip ROM and velocity range in the walk forward and walk back phases loaded onto PC10 and PC11, respectively. Furthermore, PC9 included ankle ROM and velocity range during the walk forward phase in the transverse plane. An increased ankle plantar-flexor moment has been reported in elderly fallers as a movement strategy to enhance stability during sit-to-walk (Chen et al., 2013). However, research on the role of ankle kinematics in the transverse plane during this transition remains limited.

PC2 included the frontal and sagittal trunk velocity range and frontal trunk ROM during the turn phase. This substantial contribution to variance may be attributed to the turning strategies adopted by older adults, such as lower body inclination angles, longer trajectory lengths, and larger turning radius compared to younger adults (Kurosawa et al., 2020). The findings from PC8, which included mediolateral CoM displacement in the turn phase, further support these observations.

The third component was associated with sagittal knee and hip velocity range during the sit-to-walk phase. Sit-to-walk is a critical activity of daily living, as gait initiation occurs immediately after standing, making this transition functionally significant (Perera et al., 2022). As previously noted, older adults adopt a compensatory and conservative strategy, reaching an upright position with a brief pause before initiating gait (Perera et al., 2022). The variance captured in this component may reflect differences in this strategy, as well as the maintenance of a neuromuscular reserve threshold to cope with movement uncertainties, which enables compensation before encountering physical limitations (van der Kruk et al., 2022). Prior research has also reported significantly reduced mean hip flexion ROM in elderly men compared to younger adults (van der Kruk et al., 2022). Furthermore, studies on the sit-to-stand task, which has been more extensively explored in the literature than sit-to-walk (Perera et al., 2022), have documented higher peak electromyography amplitudes of tibialis anterior, vastus medialis, rectus femoris, biceps femoris, adductor longus, gluteus maximus, gluteus medius, erector spine in older adults compared to young adults (Sadeh et al., 2023). Additionally, older adults exhibit higher trunk flexion angular velocity during sit-to-stand (Sadeh et al., 2023), which may explain the variance identified in PC6, encompassing tri-dimensional trunk velocity range. These findings reinforces the necessity of exploring the frontal and transverse planes, despite both sit-to-walk and sit-to-stand tasks being bipodal movements primarily characterized by kinematic changes in the sagittal plane (Fotoohabadi et al., 2010; Sadeh et al., 2023)

The loading of tri-dimensional trunk velocity range was also observed during the walk back phase (PC4), underscoring the significant role of trunk kinematics in older adults' performance. A recent study suggest that gait-related differences in trunk kinematics emerge as early as 60 years of age, preceding the commonly used gait indicator of walking speed, which typically declines at around 80 years, and decreased trunk rotations might be an early sign of age-related decline (Van Criekinge et al., 2024). Furthermore, older adults exhibit reduced trunk rotations, smaller movements in the frontal plane, and a more flexed trunk posture during walking (Van Criekinge et al., 2024).

PC5 included transverse knee ROM and velocity range, along with frontal knee ROM during the turn phase. This aligns with previous research indicating that pivoting during walking involves greater internal–external rotation than straight-line gait (Kefala et al., 2017).

PC7 included vertical CoM displacement during turn-to-sit, which may be related to the variance in older adults' knee and lateral lumbar flexion during this phase, both of which tend to decrease with age (Kuo et al., 2014; Lin et al., 2014).

The analysis of the differences between older adults with and without functional disability revealed variations in PC1 and PC4 scores. As previously noted, PC1 encompasses a set of variables from the walk forward, turn and walk back phases, primarily related to sagittal hip kinematics. Although comparative kinematic analysis between older adults with and without functional disability are limited, it can be argued that differences in PC scores may be associated with variations in the ability of lower limb muscles ability to contract in a time-synchronized manner (Ziegl et al., 2021). Additionally, hip abduction strength has been identified as a predictor of disability (Coyle et al., 2021), which may further explain this differences.

Another distinguishing component between older adults with and without functional disability included tri-dimensional trunk velocity range during the walk back phase (PC4). The present study sample has a mean age of 67.86 years. As previously noted, differences in trunk kinematics emerge as early as 60 years of age, with decreased trunk rotations might serving as an early indicator of age-related decline (Van Criekinge et al., 2024) and, according to the present results also for functional decline.

Despite the innovative insights presented, the results of this study should be interpreted considering its limitations. The exclusion of individuals who were unable to perform the TuG test without upper limb assistance restricted the profile of older adults with functional disability. However, in the present study, participants were required to complete the task independently and without additional movement compensation to ensure the accurate computation of a TuG PCM that characterized globally older adults performance. Additionally, the lack of consensus in the literature regarding the optimal method for segmenting the TuG necessitated the integration of different approaches to better capture older adults' movement patterns. Nevertheless, the segmentation procedures were described in detail, ensuring the study's reproducibility.

This study introduces a novel approach to TuG assessment by evaluating not only temporal parameters but also the kinematics of the lower limbs and trunk segments. This method enabled the identification of key kinematic variables in each phase and provided a comprehensive description of older adults' movement profiles during the task, as well as the kinematic differences between older adults with and without disability. Future research may incorporate the analysis of head and upper limb movements, as these segments could influence test performance and facilitate the inclusion of older adults who require upper limb support to rise from or sit on a chair.

This study provides a novel approach to the assessment of the TuG test by incorporating both temporal parameters analysis and the PCA of the kinematics of lower limb, trunk and CoM. Older adults with functional disability took significantly longer to complete TuG test and the sit-to-walk, walk forward and walk back phases. A PCM of the TuG task was computed for 38 retained variables from the TuG phases PCMs, yielding 11 PC that collectively explained 84.33% of the total variance. The increased reliance on compensatory strategies, particularly in the sit-to-walk and turn phases, suggests a prioritization of stability at the cost of efficiency. The findings highlight key differences in movement patterns between older adults with and without functional disability, particularly in sagittal hip kinematics and tri-dimensional trunk velocity. Furthermore, the results emphasize the role of trunk kinematics as a potential early indicator of functional disability.

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Declaration of Interest

The authors report there are no competing interests to declare.

Data availability statement

The dataset generated and/or analyzed during the current study is not publicly available due to confidentiality of the data.

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CHAPTER VI - General Discussion

The *General Discussion* chapter presents reflections on the overall findings of this doctoral thesis and is structured into five main sections. First, it addresses the findings from the systematic and scoping reviews and their contributions to the protocol for the cross-sectional studies. Next, the analysis of the cross-sectional studies is divided into two key areas: the biomechanical domains characterizing older adults' movement and the biomechanical domain differences associated with functional disability. Finally, the chapter examines the limitations of the thesis and outlines future research directions.

The aging global population presents significant health and societal challenges, making it essential to advance scientific research. Accordingly, this doctoral thesis aimed to advance the scientific knowledge by investigating the "Study and Analysis of Biomechanical Parameters of Human Movement Based on Disability Indicators in Older Adults through Multifactorial Analysis". As population aging intensifies, understanding the associated decline in functional capacity and disability becomes increasingly critical. There is a pressing need for research to refine the definitions of disability and to analyze the movement patterns of community-dwelling older adults. Such studies contribute to a deeper understanding of age-related biomechanical changes and aid in identifying mobility-related disability. In response to this need, the present thesis intended to generate new scientific insights by conducting an extensive literature review, establishing a strong theoretical foundation for research. Subsequently, cross-sectional studies were designed to address the primary research objective, the identifying biomechanical determinants from various functional tasks that characterize movement in older adults and distinguishing performance between those with and without functional disability.

VI.1 Systematic and Scoping Reviews

The analysis and findings from the first three studies presented in the preceding chapter have played a crucial role in achieving the objectives outlined for the literature review and this doctoral thesis. In particular, these studies have contributed to a deeper understanding of (i) the functional disability indicators of community-dwelling older adults, along with the respective instruments (study I); (ii) the existing evidence on the application of PCA in studying older adults' movement (study II), and (iii) the current guidelines for assessing specific components of older adults' movement (study III).

The first systematic review, identified key disability indicators and assessment measures, addressing the lack of consensus on definitions and evaluation methods of disability. Several relevant outcomes were gathered, which can be utilized by researchers conducting disability-related studies and by healthcare professionals in clinical settings to assess or identify older adults with, or at risk of developing, functional disability. These specialists can benefit from a comprehensive list of indicators that provides insights into the number and quality of studies incorporating these markers. Notably, gait speed emerged as one of the most frequently used indicators. This measure has been recognized as a strong predictor of disability (Abe et al., 2019; Artaud et al., 2015; Brach et al., 2007; Perera et al., 2016), and should therefore be integrated into disability status assessments. However, for the purposes of the cross-sectional studies in this thesis, the integration of gait speed as a differentiating indicator of functional disability was deemed inappropriate. The performance on this task would be biomechanically analyzed, and the introduction of correlations with other gait-related parameters would be probable, potentially influencing the study results. Moreover, temporal measures were included in the PCA of the gait task (study IV), revealing differences between functional disability groups in the Pace domain, specifically in step time, stance time, and swing time.

Cognitive function was also identified in the systematic review as an important indicator of disability that should be considered in disability assessments. However, in this research, it was established as an eligibility criterion rather than a direct assessment variable. This decision was necessary because certain disability assessment measures require participant comprehension. Furthermore, the optoelectronic system used to evaluate older adults in various tasks necessitated that participants fully understand the given instructions. Additionally, the inclusion criteria for participants, particularly community-dwelling older adults who could independently perform the selected tasks, further influenced this decision.

Based on the number and quality of studies that included disability indicators, the key differentiating factors used to classify older adults with and without disability were HGS, balance, SRH, independence on ADL, and IADL performance. These indicators provided a comprehensive characterization of disability based on body functions, activities and participation domains of the ICF. Nevertheless, as highlighted in the study I, a complete disability evaluation should incorporate all ICF domains. The systematic review findings underscored the limited use of indicators related to environmental factors and body structures, which was also reflected in the measures selected for the cross-sectional studies in this thesis. Consequently, in Studies IV to VII, the term "functional disability" was adopted (Yau et al., 2022), as the disability was primary characterized based on body functions, activities and participation domains.

Study II addressed its primary objective by providing insights into how PCA has been applied to older adults' movement data. This knowledge was also essential in constructing the PCM for each task. Specifically, the findings revealed that PCA has primarily been applied to gait and quiet standing tasks, analyzing spatiotemporal parameters, ROM or GRF. This review facilitated an expansion of the scope to include other tasks and outcomes.

Among the synthesized information in this review was the sample size of included studies, which ranged from 14 participants, with only seven in the older adult group (Park et al., 2011) to 239 participants, of whom 127 were older adults (Zhou et al., 2020). Notably, more than half of the reviewed studies had sample sizes below 50 participants, divided into groups of young and older adults. These findings, along with prior literature recommending a minimum sample size suitable for PCA (Osborne & Costello, 2004), established the necessity of including at least 50 older adult participants in the cross-sectional studies.

Most of the reviewed studies included full gait cycle data, which, combined with prior biomechanical knowledge on age-related gait changes, allowed for an in-depth analysis of gait parameters. However, applying this approach to other functional tasks, which are less frequently studied in the literature, posed challenges. For instance, a study examining two functional daily tasks employed a more conservative approach using discrete measures (Gulde et al., 2019). These insights into different methodological approaches informed the strategy for selecting outcome measures across the analyzed tasks. This also added the necessity of searching for the existence of previous PCMs on biomechanical performance of older adults along the different tasks, and search literature for the main outcomes influenced by age on the performance of the several tasks.

Study III, which compiled existing guidelines on older adults' movement assessment, revealed established protocols for assessing gait spatiotemporal parameters, primarily using electronic walkways. This scoping review provided essential guidance for designing the protocol of cross-sectional studies. The guidelines reinforce the importance of collecting information about fall history, medication use, and global cognitive function. It also highlighted the need to ensure an appropriate assessment environment, particularly a quiet, well-lit environment and participants wearing their usual footwear and nonrestrictive clothing. Furthermore, it emphasized the necessity of providing simple, clear, and standardized instructions for walking tasks, which was transposed for the other tasks. In designing the protocol for the gait cross-sectional study, these recommendations were incorporated, ensuring that steady-state walking was assessed by positioning acceleration and deceleration phases outside the measurement frames and evaluating the usual self-selected walking speed.

Collectively, these original review studies not only fulfilled their primary objectives but also laid the foundation for the subsequent cross-sectional studies conducted in this doctoral research. Nonetheless, additional investigations were necessary to support the selection of outcome measures. This process was systematized for all tasks, primarily through literature searches for studies applying PCA to the relevant tasks and systematic reviews on disability or age-related biomechanical analyses. This step proved essential in identifying alternative PCA approaches. Study II employed a search strategy with a comparator group of young adults (less than 60 years), meaning that some PCA methodologies were not included in the review. For example, the factor analysis approach used by Lord and colleagues (Lord et al., 2013) was excluded despite its relevance to gait modeling in older adults, as it did not include a younger adult comparison group. Similarly, Hollman and colleagues' study was excluded for the same reason (Hollman et al., 2011). Nevertheless, insights from these prior models were incorporated, and the literature review identified additional parameters strongly associated with aging. Accordingly, an integrative approach was adopted, incorporating information from previous models, age-associated parameters, and less frequently studied potential biomechanical parameters.

This systematized search process ultimately informed the methodological decisions regarding outcome selection for Studies V to VII.

VI.2 Cross-sectional studies – Older adults biomechanical domains of the tasks

Following the completion of the three systematic reviews and a complementary literature search, the necessary information was established to design the cross-sectional studies. This set of four studies aimed to identify biomechanical determinants from older adults performance of gait, stair negotiation and transition with floor, Sit-TS, Stand-TS, and TuG. Additionally, these studies sought to determine which parameters distinguished individuals with and without functional disability.

This research employed a multidimensional approach, grouping movement characteristics into domains rather than relying on a single measure, thus providing a holistic understanding of community-dwelling older adults' movement performance. While PCA is a powerful tool for dimensionality reduction, the interpretation of the PCs can be complex and may not always directly correspond to clinically meaningful constructs. Therefore, the PCA results were interpreted in relation to previous studies on the topic, as well as anatomical, biological, and biomechanical principles relevant to this research field.

The movement characterization models for older adults explained more than 80% of the variance for all tasks, except for the models constructed for CoM displacement and velocity range during stair negotiation and floor transitions. In studies where total variance was used as a criterion for retaining PCs, 70% is a commonly applied, albeit somewhat subjective, cut-off point (Jolliffe & Cadima, 2016). The number of parameters retained in the final PC models ranged from 28 in the Stand-TS model to 38 in the TuG model, excluding the individual models for stair negotiation. Due to these differences in methodology, the gait, Sit-TS, Stand-TS, and TuG models are discussed in an integrated manner, while stair negotiation is analyzed separately in relation to the findings from other tasks.

For the gait, Sit-TS, Stand-TS, and TuG models, the first three PCs accounted for more than half of the total variance explained by the models, with their cumulative variance ranging from 41.26% in the Stand-TS model to 47.61% in the gait model.

The first PC, which accounted for the largest proportion of variance, was associated with Pace (step time, stance time, and swing time) for gait; transverse hip and knee kinematics during the stabilization phase of Sit-TS; transverse knee and frontal hip and knee velocity range during the flexion phase of Stand-TS; and hip and knee kinematics and CoM velocity during the walk-back, walk-forward, and turn phases of the TuG. As previously discussed, the predominance of temporal measures in gait is consistent with prior research recognizing gait speed as a strong predictor of disability (Abe et al., 2019; Artaud et al., 2015; Brach et al., 2007; Perera et al., 2016).

The aggregated findings from the first components of Sit-TS, Stand-TS, and TuG highlight the critical role of hip and knee control. The relevance of hip kinematics in these tasks may be attributed to age-related weakening of the hip abductors, which is known to impact gait performance (Gordon et al., 2014), and may also affect the execution of other functional tasks. Recent research indicates that older adults experience a significant reduction in their ability to generate hip abduction torque, power, and velocity, which correlates with lower scores on clinical assessments compared to younger adults (Lanza et al., 2024). Additionally, decreased hip abductor strength has been linked to deficits in balance and functionality in older adults (Porto et al., 2019). These findings, in conjunction with the results of this thesis, underscore the need for targeted interventions to strengthen the hip abductors in order to maintain functional independence in older adults, particularly in tasks related to daily living activities.

The second PC in the gait task was primarily associated with variability measures, including step time variability, stance time variability, swing time variability, and step velocity variability. Previous studies emphasize the significance of these measures, as they have the potential to detect changes in the motor control system's capacity to adapt to environmental and task constraints (Stergiou & Decker, 2011), even when the subsystems contributing to gait variability exhibit only subtle changes (Hausdorff et al., 2001). For Sit-TS, Stand-TS, and TuG, the second PC predominantly captured trunk kinematics. Specifically, trunk motion was highlighted during the flexion phase of Sit-TS, the extension phase of Stand-TS, and the turn phase of TuG. A recent systematic review reported increased trunk flexion in older adults compared to younger individuals during Sit-TS and emphasized the need for comprehensive analyses of movements in the frontal and transverse planes (Sadeh et al., 2023). This need is further reinforced by the prominence of both sagittal and frontal trunk kinematics in Stand-TS, as well as the tri-dimensional trunk kinematics observed in the turn phase of TuG.

The third principal component in gait analysis, grouped the kinetic measures associated with the push-off phase of the gait, specifically sagittal peak ankle power, the second peak of vertical GRF, and the AP GRF peak. This represents a novel domain in comparison to previous works (Hollman et al., 2011; Lord et al., 2013; Verghese et al., 2008). The emergence of this component as a key factor, as discussed in Study IV, may be related to the reduction in ankle push-off power (Sloot et al., 2021), plantar flexor muscle weakness, and the underutilization of available muscular capacity (Franz, 2016).For Sit-TS and TuG, the third PC was primarily associated with sagittal hip and knee kinematics during the extension and sit to walk phases. This similarity suggests the presence of a compensatory and conservative strategy in which older adults adopt a sit-to-stand-and-walk approach, achieving an upright posture and briefly pausing before initiating gait (Perera et al., 2022). This strategy likely contributes to the biomechanical parallels between these two tasks. A key differentiating factor in the Sit-TS model was the integration of sagittal and transverse ankle velocity range during the extension phase. Previous research has reported higher activation of the soleus and tibialis anterior muscles in older adults compared to younger individuals during Sit-TS, possibly as a compensatory mechanism for reduced trunk flexion during the task (Sadeh et al., 2023; van der Kruk et al., 2021). Further analysis of muscle activity during TuG would be valuable, as the sixth PC in the TuG model also highlighted tri-dimensional trunk velocity range, suggesting the presence of compensatory mechanisms.

The fourth and subsequent PCs accounted for less variance but provided valuable insights into task performance and the biomechanical parameters distinguishing older adults with and without functional disability.

For the stairs negotiation individual PCMs, although the approach differed slightly, the biomechanically meaningful parameters aligned with the findings from previous tasks. Key parameters, such as angular velocity, particularly within the hip and knee sagittal plan, were consistently retained. These parameters were present in models analyzing both foot contact with the step and subsequent lift-off, as well as in models assessing ROM. A similar predominance of these variables was also observed in transitions with the floor.

Overall, this set of analyses highlighted the importance of hip and knee control, temporal and variability measures, and trunk kinematics in characterizing older adults' movement. Across gait, Sit-TS, Stand-TS, TuG, stair negotiation, and floor transitions, consistent biomechanical patterns emerged, emphasizing the role of hip abductors, compensatory strategies, and push-off kinetics.

VI.3 Cross-sectional studies –Biomechanical domains differentiators of functional disability

The differentiating biomechanical parameters of older adults with and without disability emerged in all comparative analyses of the PCs integrated into the task-specific PCMs, except for the Sit-TS task. These distinguishing domains were identified in the first PC for both gait and TuG tasks.

In gait, the differentiating domain was named Pace, encompassing step time, stance time, and swing time, similar to previous models (Lord et al., 2013). Older adults with disability exhibited increased durations for these parameters, aligning with evidence that identifies gait speed as a strong indicator of disability and other adverse outcomes (Abe et al., 2019; Cesari et al., 2009). Among these parameters, stance time showed the greatest disparity between groups, suggesting that older adults with functional disability adopt a strategy of prolonging the support phase of each limb during gait.

In the TuG task, the first PC comprised parameters from multiple phases. Notably, the phases included are the walking transitions between the other phases that are more explored in literature (Bovonsunthonchai et al., 2015; Lin et al., 2014; Madrid et al., 2023; Perera et al., 2022; Thigpen et al., 2000). Moreover, sagittal hip kinematics emerged as a key factor during the walk-back and walk-forward phases, emphasizing the importance of hip joint control. Hip control was also identified as a distinguishing domain in gait, appearing in the 9th PC, though in this case, it pertained to frontal plane control during key gait events, the HS and TO. Analysis of hip behavior of both groups throughout the gait cycle revealed that older adults with functional disability exhibit greater hip adduction and reduced ROM compared to their non-disabled counterparts. Consistent with these findings, maximum voluntary isometric strength and rate of force generation in the hip abductors have been shown to effectively distinguish between older fallers and non-fallers (Gafner et al., 2020). More importantly, hip abduction strength has been identified as a predictor of disability (Coyle et al., 2021). These findings, reinforced by the functional disability-differentiating PCs in gait and TuG, support the hypothesis that physiological changes in hip control may be more pronounced in older adults with functional disability.

The fourth component of the TuG PCM also distinguishes functional disability, incorporating tri-dimensional trunk velocity range during the walk back phase. Reduced trunk rotations have been identified as an early indicator of age-related decline (Van Criekinge et al., 2024) and, according to the findings of study VII they may also serve as an indicator of functional decline. This is further supported by the ninth PC of the Stand-TS task, which included sagittal and frontal trunk velocity range during the momentum transfer phase and also differentiated between groups.

An additional PC in the Stand-TS task also distinguished older adults with and without disability. However, caution is needed in its interpretation, as none of the integrated variables had loadings higher than 0.8. Nevertheless, variables with loadings above 0.7 included knee and hip velocity ranges during the momentum transfer phase, reinforcing the importance of focusing on this phase in assessment and intervention programs for older adults with functional disability.

The individual PCMs developed for the stair negotiation task revealed that the key biomechanical parameters characterizing older adults' performance also served as differentiators of functional disability. Specifically, the analysis of angular velocities at the hip and knee joints showed that older adults with disabilities exhibited lower values compared to their non-disabled peers.

Overall, the analysis highlighted key biomechanical differences between older adults with and without functional disability, particularly in gait, TuG, Stand-TS, and stair negotiation tasks. Pace-related parameters, hip control, trunk kinematics, and joint velocity ranges emerged as critical differentiators, emphasizing the importance of assessing these factors in functional disability evaluations and intervention programs.

VI.4 Limitations of the thesis

This thesis presents a comprehensive examination of functional disability, addressing a critical issue in aging research by exploring the biomechanical determinants of movement in older adults and distinguishing between those with and without functional disability. Despite efforts to minimize bias throughout the research, certain limitations must be acknowledged.

Firstly, studies IV to VII rely on a cross-sectional design, assessing movement performance at a single point in time, which limits the ability to establish causality or track changes over time. However, strict planning and adherence to guidelines, from study registration on ClinicalTrials.gov to data analysis and interpretation, ensured the highest possible quality for this study design.

The sample size of the cross-sectional studies, while larger than many biomechanical studies using gold-standard movement analysis systems (Boyer et al., 2017), and those included in systematic review II, remains a limitation for PCA. In study II, more than half of the included studies had sample sizes below 50 participants, restricting the interpretation of their results. Recognizing these constraints, efforts were made to increase the sample size despite the challenges of recruiting older adults for assessments involving advanced movement analysis systems. In-person project presentations helped demystify the complexity of these procedures, facilitating the recruitment of a larger sample. Nevertheless, a larger and more diverse cohort would enhance the generalizability of the findings.

Another limitation to consider is that this thesis does not fully assess disability across all domains of the ICF, as it does not incorporate detailed analyses of body structures and environmental factors. While the systematic review highlighted a general underassessment of environmental measures and a focus on body structures in specific conditions, this omission may impact the external validity of the findings.

Finally, sample characterization revealed no significant differences between older adults with and without disability, except for polypharmacy. In systematic review I, this indicator was assessed in only two studies, with just one classified as high quality. Although analyzing the number and type of medications was beyond the scope of this thesis, future research should explore their potential influence, as studies suggest an impact on task performance (Mustafaoğlu et al., 2015).

VI.5 Future directions of the research

This research project aimed to deepen knowledge and incorporate novel approaches in studying older adults' movement and functional disability. However, science, particularly in the fields of physiotherapy and biomechanics, is constantly evolving, and the findings of this doctoral thesis suggest several future research directions.

A longitudinal study with follow-up assessments could help determine whether the identified movement patterns predict future disability progression, thereby validating and refining previous findings. Additionally, integrating biomechanical measures from different tasks into a single model could enhance understanding of the most critical movement characteristics in older adults' daily activities.

Recent literature has begun addressing gaps identified in the systematic review on the applicability of PCA in analyzing older adults' movement performance. Studies have applied factor analysis to identify distinct gait domains (Hagoort et al., 2023) and expanded analyses beyond gait to other tasks (Haraguchi et al., 2023). Accordingly, combining data from multiple studies could help overcome the sample size limitations frequently encountered in this field.

Furthermore, applying PCA or machine learning methods to complete task cycle data, focusing on the key parameters highlighted by discrete PCA in this and other studies, could further enhance insights into movement characterization and functional disability differentiation in older adults.

CHAPTERVII - Conclusions

The chapter *Conclusions* summarizes and synthesize the key findings of the doctoral thesis, providing an overall perspective on the work. This chapter includes also a topic on the main contributions for the scientific research.

The challenges and opportunities in the field of older adults' movement characterization and functional disability differentiation served as the foundation for establishing the main goal of this doctoral thesis and conducting studies I to VII. The combination of systematic and scoping reviews contributed to the scientific understanding of this topic while also providing methodological guidance for the subsequent cross-sectional studies.

Systematic Review I identified key disability indicators, such as gait speed, handgrip strength, balance, and self-reported health, that form the basis for understanding functional disability in older adults. These findings highlight the necessity of a comprehensive, multidimensional approach to disability assessment. Study II revealed that PCA has been predominantly applied to gait and quiet standing tasks, focusing mainly on spatiotemporal parameters. Study III reported guidelines for assessing gait spatiotemporal parameters, primarily through electronic walkways use.

The set of cross-sectional studies used PCA to group older adults' biomechanical performance characteristics into domains, revealing structural relationships among variables. Gait Pace and Frontal Hip Control distinguished functional disability, and stairs negotiation analysis established foundational insights, emphasizing the role of hip and knee sagittal angular velocity. Additionally, the importance of Stand-TS task was underscored, with differences between groups in transverse knee, as well as frontal hip kinematics and sagittal and frontal trunk angular velocity ranges. The TuG PCM highlighted sagittal hip kinematics during the walk back and walk forward phases. Furthermore, TUG trunk kinematics emerged as a potential early indicator of functional disability.

The integration of multiple functional tasks (gait, Sit-TS, Stand-TS, and TuG) using PCA combined biomechanical data and revealed that a few key components can capture most of the variance in movement performance. This approach not only streamlines the analysis but also effectively differentiates between older adults with and without functional disability. Across the tasks, specific biomechanical parameters, such as temporal measures (pace-related metrics), hip and knee kinematics, and trunk dynamics, consistently distinguish individuals with functional disability from those without. These differences highlight potential targets for interventions aimed at improving movement efficiency and maintaining independence in older adults.

VII.1 Main contributions of the doctoral thesis

In pursuit of fulfilling the primary objective of this doctoral thesis, several valuable contributions were made to science, physiotherapy, and society.

Firstly, this research gathered a comprehensive set of indicators, both in quantitative and qualitative terms, along with their respective instruments. These indicators can be utilized in research to distinguish clusters of individuals with functional disabilities and in clinical practice to identify emerging cases, or those at risk, of developing such functional disability. This thesis aimed to advance scientific knowledge by examining age-related modifications and functional impairments from a biomechanical and multidimensional perspective. Kinematic and kinetic variables were analyzed and grouped into different domains to provide a more holistic understanding of these processes.

Additionally, the knowledge developed across multidimensional domains aimed to contribute to technological advancements. The biomechanical characteristics of older adults identified in this research hold potential value for integration into telemonitoring systems designed to assess older adults during daily activities.

The methodological insights obtained through systematic reviews and preliminary findings from cross-sectional studies were incorporated into a funded scientific project, Safe Health Elderly Monitoring (SAFHE). This project aimed to develop a wearable device equipped with multiple biological sensors that are both clinically relevant and user-friendly. The device was designed to function in conjunction with an environmental control station, employing artificial intelligence and machine learning techniques to enable the remote detection of pathological conditions and the continuous monitoring of older adults in their home environments. SAFHE was developed in collaboration with the Polytechnic of Porto (E2S and PORTIC), the University of Turku (Finland), Plux – Wireless Biosignals, S.A., and the Polytechnic University of Cávado and Ave.

Furthermore, the knowledge generated through this doctoral thesis has been extended and refined through the development of two undergraduate final projects and two master's dissertations, specifically:

- Applicability of Principal Component Analysis in the Study of Movement in the Older Adult Population – Systematic Review
  Bruno Pereira Genízio da Silva, Hugo Miguel Gaifém Faria

Degree in Physiotherapy, E2S, Polytechnic of Porto, 2022

- Analysis of Spatiotemporal Parameters and Variation in the Center of Pressure During Walking in Older Adults with and without a History of Falls
  Gonçalo Pina, Manuela Matias, and Maria Mesquita
  Degree in Physiotherapy, E2S, Polytechnic of Porto, 2023
- Association Between the History of Falls and the Fear of Falling in Stair Descent and Gait Transition: Spatiotemporal and Lower Limb Kinetics and Kinematics in Older Adults – An Observational Study
  Ivone da Silva Teles
  Master's Degree in Physiotherapy, Neurology Option, E2S, Polytechnic of Porto, 2023
- Association Between Lower Limb Intra- and Intersegmental Coordination During Gait and Fear of Falling History in Older Adults
  Márcia Paula Faria Castro
  Master's Degree in Physiotherapy, Neurology Option, E2S, Polytechnic of Porto, 2024

In alignment with the best research practices, the findings of this doctoral thesis have also been disseminated at scientific events, including:

- Presentation of the preliminary findings from Study II at *SEIA Conference - 8th International Conference on Sensors Engineering and Electronics Instrumentation Advances (SEIA' 2022)*, held in Corfu, Greece, from September 21 to 23, 2022.
- Presentation of preliminary doctoral thesis findings at the international workshop "*Technology-based multidisciplinary cooperation and its applications for improving well-being (TEMUCO 2023)*" held in Chartres, France, from June 12 to 14, 2023.
- Presentation of doctoral thesis to a broader audience, culminating in reaching the finals of the Three Minute Thesis (3MT®), University of Porto, Portugal

Through these contributions, this thesis has sought to advance scientific knowledge, enhance clinical practice, and foster technological innovation in the field of physiotherapy while remaining mindful of the broader societal impact.

CHAPTER VIII – References

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Appendices

Appendix I - Sample selection questionnaire

Movement Older Adults
Biomechanical Analysis

Questionário seleção da amostra do estudo: Estudo e análise de parâmetros biomecânicos do movimento humano baseado em indicadores de incapacidade em adultos mais velhos através de uma análise multifatorial

Este questionário insere-se no âmbito dos trabalhos incluídos no projeto de doutoramento denominado "Estudo e análise de parâmetros biomecânicos do movimento humano baseado em indicadores de incapacidade em adultos mais velhos através de uma análise multifatorial".
Este estudo pretende identificar determinantes biomecânicos a partir de diferentes tarefas funcionais tendo em consideração indicadores de incapacidade em adultos mais velhos, através de uma análise comparativa entre grupos com diferentes indicadores. Pretende-se ainda identificar quais dos indicadores são preditores de desenvolvimento ou alterações na incapacidade.
A participação no estudo envolve a resposta a questionários sobre as suas atividades de vida diária e a realização de diferentes tarefas funcionais como a caminhar, sentar e levantar e subir e descer escadas.

A sua participação é voluntária, podendo desistir em qualquer altura do estudo. A equipa de investigação garantirá durante todo o processo o anonimato dos seus dados. Pretende-se que os resultados do presente estudo sejam publicados em revistas científicas e divulgados em congressos da especialidade, sempre mantendo a confidencialidade dos dados dos participantes.

Desde já agradecemos a disponibilidade para o preenchimento do questionário,

A equipa de investigação
Juliana Moreira (Msc)
Andreia Sousa (PhD)
Rubim Santos (PhD)

Projeto de Doutoramento Financiado pela
Fundação para a Ciência e Tecnologia
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1. Qual a sua idade? (Indique o número de anos): *

A sua resposta

2. Qual o seu género? *

- ○ Feminino
- ○ Masculino
- ○ Outro

3. Qual o seu peso (em kilogramas)? *

A sua resposta

4. Qual a sua altura (em metros)? *

A sua resposta

5. Quais as suas Habilitações Literárias (Selecione a opção mais adequada): *

- ○ Não sabe ler nem escrever
- ○ Sabe ler e escrever
- ○ Ensino Primário incompleto
- ○ Ensino Primário/ 1º ciclo (4ª classe)
- ○ Ensino Básico Incompleto/ 2º ciclo (6º ano)
- ○ Ensino Básico/ 3º ciclo (9º ano)
- ○ Ensino Secundário (12º ano)
- ○ Ensino Superior (licenciatura, mestrado ou doutoramento)

6. Atualmente, qual a sua situação profissional (Selecione a opção mais adequada): *

- ◯ Empregado
- ◯ Desempregado
- ◯ Reformado
- ◯ Outro

7. Qual o seu Estado Civil (Selecione a opção mais adequada): *

- ◯ Solteiro
- ◯ Casado
- ◯ Viúvo
- ◯ União de facto
- ◯ Divorciado/Separado
- ◯ Outro

8. Qual é o seu tipo de Habitação? (Selecione a opção mais adequada) *

- ◯ Morada familiar
- ◯ Residência/lar

9. Indique se o seu médico lhe diagnosticou algumas das seguintes condições de saúde? Pode assinalar várias, caso seja necessário. *

- [ ] História de Acidente Vascular Cerebral (AVC)
- [ ] História de hemorragia cerebral
- [ ] História de traumatismo craniano
- [ ] Doença de Parkinson
- [ ] Doença de Alzheimer
- [ ] Insuficiência cardíaca
- [ ] Insuficiência renal
- [ ] Insuficiência Hepática
- [ ] Cancro
- [ ] Artrite reumatoide
- [ ] Osteoartrose
- [ ] Fratura dos membros inferiores à menos de 6 semanas
- [ ] Pé diabético
- [ ] Outra
- [ ] Nenhuma

9.1 Se indicou outra. Qual?

A sua resposta

10. Utiliza algum aparelho para o ajudar a deslocar-se? *

- ○ Todos os dias
- ○ Por vezes
- ○ Nunca

10.1 Se utiliza, qual?

- ○ Bengala
- ○ Candianas
- ○ Andarilho
- ○ Cadeira de Rodas
- ○ Outro

10.1.1 Se indicou outro. Qual?

A sua resposta

11. Toma medicação? *

- ◯ Sim
- ◯ Não

12. Qual a sua capacidade de visão (se for o caso, utilizando óculos ou lentes)? *

- ◯ Normal
- ◯ Consegue reconhecer o rosto de uma pessoa a aproximadamente 1 metro de distância
- ◯ Incapaz ou quase incapaz de ver

13. Qual é a sua capacidade auditiva (se for o caso com o seu aparelho auditivo)? *

- ◯ Sem dificuldade na comunicação diária
- ◯ Apenas consegue ouvir vozes ou sons altos
- ◯ Incapaz ou quase incapaz de ouvir

14. Estaria disponível para participar no estudo apresentado, sabendo que a sua participação é voluntária e que a qualquer momento poderá decidir cessar a sua colaboração? *

- ◯ Sim
- ◯ Não

15. Se respondeu sim, indique como gostaria de ser contactado?

- ◯ Telemóvel
- ◯ Telefone
- ◯ E-mail

Appendix II – Dissemination Informative flyer

Tem 60 ou mais anos? Então poderá participar neste estudo de investigação!

Movement Older Adults Biomechanical Analysis

Acerca do estudo:

O estudo MOBA pretende identificar determinantes biomecânicos a partir de diferentes tarefas funcionais, que sejam indicadores ou preditores de incapacidade em adultos mais velhos.

Quem pode participar?

Poderão participar todas as pessoas com 60 ou mais anos de idade que aceitem participar voluntariamente e reúnam os critérios de inclusão identificados no questionário de seleção.

O que o participante irá fazer?

O participante responderá a questionários sobre a sua capacidade para realizar atividades de vida diária e realizará tarefas como o sentar/levantar, caminhar ou subir e descer escadas, enquanto o movimento é captado por câmaras especializadas na recolha do movimento humano.

Para mais informações contactar a equipa de investigação:

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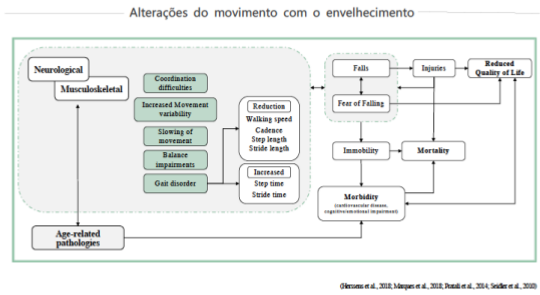
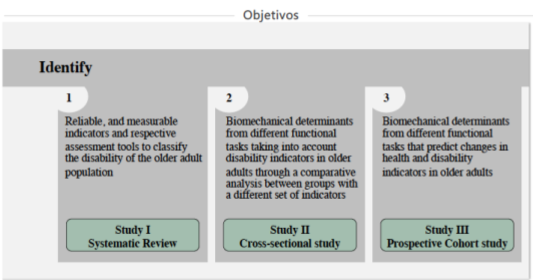
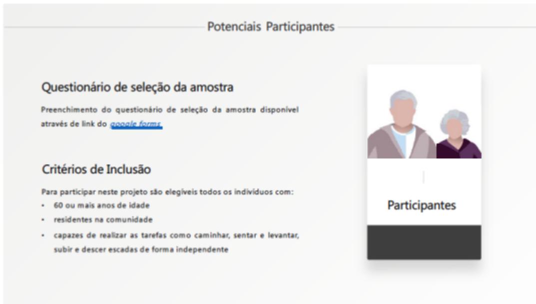
Preencher questionário de seleção

Appendix III – Dissemination Presentation



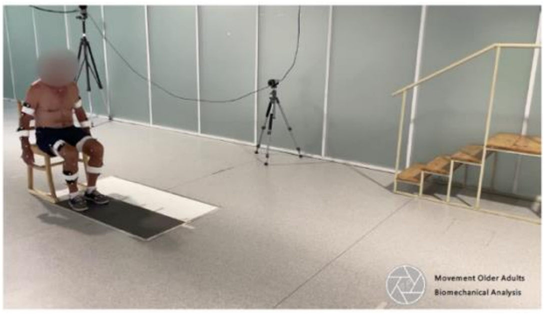




Laboratório de Análise do Movimento do Centro de Investigação em Reabilitação
Todas avaliações realizadas no mesmo laboratório
Equipamentos de avaliação validados e fiáveis

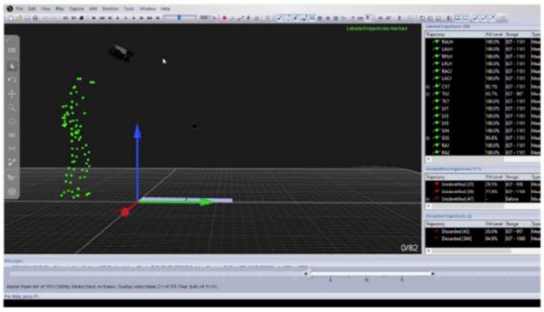
Movement Older Adults
Biomechanical Analysis

Movement Older Adults
Biomechanical Analysis



Movement Older Adults
Biomechanical Analysis

Movement Older Adults
Biomechanical Analysis



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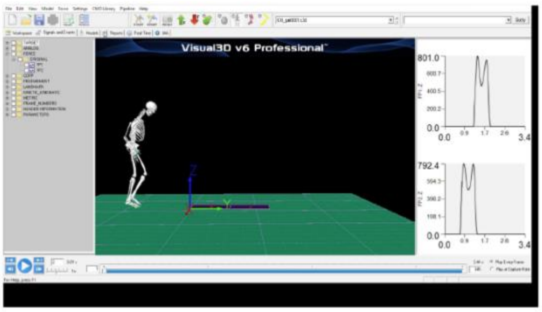


Visual3D v6 Professional
801.0
0.0
0.0
3.4
792.4
0.0
0.0
3.4

Resultados da avaliação
Relatório da avaliação
Para além da análise dos dados no âmbito do projeto e posterior divulgação em revistas e eventos científicos, será fornecido ao participante um relatório com os resultados dos elementos avaliados.
Tratamento dados
Média velocidade marcha/ valores normativos
Média 5 vezes sentar levantar/ valores normativos
Média Tempo TUG/ valores normativos

Considerações Éticas
Projeto aprovado pela Comissão de Ética da Escola Superior de Saúde do Politécnico do Porto
Anonimização dos dados garantida
Avaliação realizada por profissionais de saúde qualificados
Possibilidade de desistir em qualquer altura do estudo

Movement Older Adults
Biomechanical Analysis
Obrigada
A equipa de investigação encontra-se disponível para esclarecer quaisquer dúvidas
Juliana Moreira
Andreia SP Sousa asp@ess.ipp.pt
Rubim Santos rss@ess.ipp.pt

Appendix IV - Informed consent form

P.PORTO

ESCOLA
SUPERIOR
DE SAÚDE
POLITÉCNICO
DO PORTO

TERMO DE CONSENTIMENTO INFORMADO

Compete ao Investigador Principal, prestar aos Participantes do estudo as informações necessárias ao consentimento livre e esclarecido.
O termo de consentimento informado deve ser específico do Estudo de Investigação (o modelo deve ser adaptado ao estudo em causa, acrescentando outros dados considerados pertinentes ou eliminando partes não aplicáveis).

DESIGNAÇÃO DO ESTUDO: Estudo e análise biomecânica dos parâmetros do movimento humano baseado em indicadores de incapacidade em adultos mais velhos baseado numa análise multifatorial: um estudo observacional transversal

Declaração de Consentimento Informado

Conforme o RGPD, a Lei n.º 67/98 de 26 de Outubro e a "Declaração de Helsínquia" da Associação Médica Mundial (Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996, Edimburgo 2000; Washington 2002, Tóquio 2004, Seul 2008, Fortaleza 2013) – quando se aplicar

Eu, abaixo-assinado ____fui informado de que o Estudo de Investigação acima mencionado se destina a **identificar determinantes biomecânicos a partir de diferentes tarefas funcionais, como a marcha, o sentar e levantar ou subir e descer escadas, tendo em consideração indicadores de incapacidade em adultos mais velhos, através de uma análise comparativa entre grupos com diferentes indicadores.**

Sei que neste estudo está prevista **o preenchimento de questionários e também a realização de medição da tensão arterial, medição da composição corporal, avaliação da força manual, realização das tarefas funcionais: sentar e levantar, marcha, subir e descer escadas, levantar, caminhar três metros, voltar e sentar e manter a posição de pé**, tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado.

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome do Investigador e Contacto: Juliana dos Santos Moreira, jmo@ess.ipp.pt.

___/___/_____ ________________________________

SGS ESS.0004.MO.317.02

1 | 1

Appendix V - E2S, Polytechnic of Porto Institutional Ethics Committee Approval

P.PORTO

ESCOLA
SUPERIOR
DE SAÚDE
POLITÉCNICO
DO PORTO

PARECER DA COMISSÃO DE ÉTICA

Número de Registo da Comissão de Ética: CE0064C   Data receção do Documento: 27/04/2022.   Existência de entradas anteriores: Não

TÍTULO DO TRABALHO:

Study and analysis of biomechanical parameters of human movement based on disability indicators in older adultsbased on a multifactorial analysis: a cross-sectional study

INVESTIGADOR RESPONSÁVEL:

Juliana dos Santos Moreira

DATA PREVISTA PARA A REALIZAÇÃO DO TRABALHO: Início: 1/05/2022 Fim: 3/05/2024

RESUMO DO ESTUDO

OBJETIVOS:

Nada a referir.

AMOSTRA:

Amostra de Conveniência recrutados a partir do Center for Rehabilitation Research of the Obra Diocesana de Promoção Social (ODPS) e do SAFHE Project.

FORMULÁRIO DE DADOS A RECOLHER:

Nada a referir

MATERIAL:

Nada a referir.

MÉTODOS:

Nada a referir.

Os dados pessoais cumprirão o regulamento (UE) 2016/679 do Parlamento e do Conselho Europeu e da lei portuguesa58/2019.

O anonimato e a confidencialidade dos dados serão garantidos, uma vez que o principal investigador atribuirá um código alfanumérico aos dados dos participantes.

Além disso, os dados só serão disponibilizados em um computador protegido com uma senha conhecida apenas pelo principal investigador

RISCOS:

Não existem

CONSENTIMENTO INFORMADO:

Nada a referir.

AUTORIZAÇÃO PELOS RESPONSÁVEIS LOCAIS:

Apresenta autorização da ATC de Fisioterapia, Termo de responsabilidade de orientadores,

APRECIAÇÃO DA COMISSÃO DE ÉTICA:

Termo de Consentimento Informado. Apresenta Pedido Institucional

PARECER FINAL DA COMISSÃO DE ÉTICA

De acordo com os dados analisados, o parecer é favorável desde que cumpridas todas as diretrizes submetidas a esta Comissão, recomendando-se que a decisão seja suspensa caso haja algum incumprimento grave.

Assinado por: **PEDRO MANUEL RIBEIRO DA ROCHA MONTEIRO**
Num. de Identificação: 09132856
Data: 2022.05.27 13:42:14 +0100

25/05/2022

SGS ESS.004.MO.318.02

1 | 1

Appendix VI - Clinical Characterization Questionnaire

ID (código que garante o anonimato dos dados atribuído pela equipa de investigação) __

1. O seu médico diagnosticou-lhe alguma condição de saúde?

Sim	
Não	

1.1 Se sim, qual ou quais?____

2. Atualmente toma medicação prescrita pelo seu médico?

Sim	
Não	

2.1 Se sim, qual?

Nome	Posologia

3. Toma medicação não prescrita pelo seu médico?

Sim	
Não	

3.1 Se sim, qual?

Nome	Posologia

4. Nos últimos 12 meses recorreu a serviços de saúde?

Sim	
Não	

4.1 Se sim, qual?

Hospital	
Centro de Saúde	
Profissional de saúde em contexto domiciliar (curativos)	
Outro	

4.2 Qual o motivo?____

5. Tem medo de cair? (Selecione com um x a opção mais adequada)

Sim	
Não	

6. Caiu nos últimos 12 meses?(se a resposta for não passar para a pergunta 7.)

Sim	
Não	

6.1 Se sim, quantas vezes?(Indique um número) ________

6.2 Caiu dentro ou fora de casa?

Dentro	
Fora	

6.3 Necessitou de cuidados médicos?

Sim	
Não	

6.3.1 Se sim, que tipo de cuidado médico?

Hospital	
Centro de Saúde	
Profissional de saúde em contexto domiciliar (curativos)	
Outro	

6.3.2 Se teve intervenção hospitalar, quantos dias necessitou dos cuidados (internado e /ou curativos)? (Indique um número)__________

6.4 Teve restrição das suas atividades de vida diária? (andar, comer, higiene pessoal)

Sim	
Não	

6.4.1 Se teve restrição das suas atividades de vida diária, indique o número de dias.________

6.5 Fez alguma fratura?

Sim	
Não	

6.5.1 Se fez fratura, indique o local.

Crânio		Mão	
Coluna vertebral		Pelvis	
Costelas		Coxa	
Clavícula		Joelho	
Ombro		Perna	
Braço		Tornozelo	
Antebraço		Pé	
Punho		Outra	

6.5.2- Qual foi o motivo da queda?

Escorregar		Fraqueza dos membros inferiores	
Tropeçar		Sem motivo aparente	
Perder a consciência		Não se recorda	
Tonturas		Outro	

6.5.1.1 Se respondeu outro, qual?_______________

7. De uma forma geral como avalia a sua saúde hoje? (Selecione com um x a opção mais adequada)

Muito má	
Má	
Moderada	
Boa	
Muito boa	

Appendix VII . Mini Mental State Examination Portuguese Version

MINI MENTAL STATE EXAMINATION (Folstein, Folstein & McHugh,1975, com adaptação de Guerreiro e colaboradores, 1994)

I. ORIENTAÇÃO

Vou fazer-lhe algumas perguntas. A maior parte delas são fáceis. Tente responder o melhor que for capaz." (Dar 1 ponto por cada resposta correta)

1. Em que ano estamos? _________
2. Em que mês estamos? _________
3. Em que dia do mês estamos? _________
4. Em que estação do ano estamos? _________
5. Em que dia da semana estamos? _________
6. Em que País estamos? _________
7. Em que Distrito vive? _________
8. Em que Terra vive? _________
9. Em que casa estamos? _________
10. Em que andar estamos? _________

Nota: _________

II. RETENÇÃO

"Vou dizer-lhe três palavras. Queria que as repetisse e que procurasse decorá-las porque dentro de alguns minutos vou pedir-lhe que me diga essas três palavras." As palavras são:

PERA **GATO** **BOLA**

"Repita as três palavras". (Dar 1 ponto por cada palavra correta)

PERA ______ GATO _______ BOLA ______ Nota: _______

II. ATENÇÃO E CÁLCULO

"Agora peço-lhe que me diga quantos são 30 menos 3 e que ao número encontrado volte a subtrair 3 até eu lhe dizer para parar."

(Dar 1 ponto por cada resposta correta. Parar ao fim de 5 respostas. Se fizer um erro de subtração, mas continuando a subtrair corretamente partir do erro, conta-se como um único erro)

(30) (27) (24) (21) (18) (15) Nota: _______

IV. EVOCAÇÃO

(Só se efetua no caso do sujeito ter aprendido as três palavras referidas na prova de retenção) "Agora veja se me consegue dizer quais foram as três palavras que lhe pedi há pouco para repetir." (Dar 1 ponto por cada resposta correta)

PERA ______

GATO ______

BOLA ______ Nota: _______

V. LINGUAGEM

(Dar 1 ponto por cada resposta correta)

a) Mostrar o relógio de pulso.

"Como se chama isto?" Nota: _______

b) Mostrar um lápis.

"Como se chama isto?" Nota: _______

c) Repetir a frase:

"O rato rói a rolha" Nota: _______

d) "Vou dar-lhe uma folha de papel. Quando eu lhe entregar o papel, pegue nele com a sua mão direita, dobre-o ao meio e coloque-o no chão".

(Dar 1 ponto por cada etapa bem executada. A pontuação máxima é de 3 pontos.)

Pega no papel com a mão direita _______

Dobra o papel ao meio _______

Coloca o papel no chão _______ Nota: _______

e) "Leia e cumpra o que diz neste cartão."

Mostrar o cartão com a frase: "FECHE OS OLHOS". (Dar 1 ponto por cada realização correta).

Nota: _______

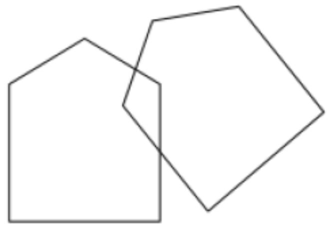
f) "Escreva uma frase."

(A frase deve ter sujeito, verbo e ter sentido para ser pontuada com 1 ponto. Erros gramaticais ou com erros de trocas de letras não contam como erros.)

Nota: _______

g) “Copie o desenho que lhe vou mostrar.” Mostrar o desenho num cartão.

(os 10 ângulos devem estar presentes e 2 deles devem estar intersectados para pontuar 1 ponto. Tremor e erros de rotação não são valorizados)



Nota: _______

NOTA TOTAL: _______

Appendix VIII – Barthel Index Activities of Daily Living

As questões que se seguem procuram avaliar a sua capacidade funcional para realizar as **actividades básicas de vida diária**. Para isso, refira para cada questão, a resposta que melhor traduz a sua situação.

Índice de Barthel	Pontuação
A. Actualmente, relativamente à sua higiene pessoal: 1☐ Consegue lavar o rosto, lavar os dentes, barbear-se, pentear-se sozinho 0☐. Precisa de ajuda para o cuidado pessoal	
B. Actualmente, consegue tomar banho: 1☐ Sozinho, entrar e sair da banheira, lavar-se, usar o chuveiro 0☐ Não consegue tomar banho sozinho	
C. Actualmente, consegue vestir-se: 2☐ Veste-se sozinho (incluindo abotoar botões, fechos,atacadores) 1☐ Precisa de ajuda para algumas coisas(ex.apertar atacadores, fechar um fecho ou abotoar) 0☐ Precisa sempre da ajuda de outra pessoa para se vestir	
D. Actualmente, consegue alimentar-se: 2☐ Desde que lhe coloquem a comida já preparada, consegue comer sozinho 1☐ Precisa de ajuda para cortar a carne, barrar a manteiga, etc. 0☐ Não consegue alimentar-se sozinho	
E. Actualmente, consegue levantar-se da cama ou de uma cadeira sozinho? 3☐ Consegue passar da cama para a cadeira sem grande dificuldade 2☐ Necessita de uma pequena ajuda (verbal ou física) 1☐ Necessita de um grande ajuda física para passar da cama para a cadeira 0☐ Incapaz de passar da cama para a cadeira, não tem equilíbrio	
F. Actualmente, consegue subir e descer escadas 2☐ Consegue subir e descer escadas 1☐ Precisa de ajuda para subir e descer escadas 0☐ Não consegue subir ou descer escadas	
G. Actualmente, consegue andar/marcha ou deslocar-se 3☐ Consegue andar (com ou sem bengala, andarilho, canadiana, etc.) 2☐ Consegue andar com ajuda (verbal ou física) de 1 pessoa 1☐ Consegue andar sozinho em cadeira de rodas 0☐ Não consegue andar, nem com ajuda de outras pessoas	
H. Actualmente, tem controlo na função intestinal 2☐ Controla bem esta função 1☐ Às vezes (ocasionalmente) não controla as fezes 0☐ Não controla as fezes, ou só evacua com a ajuda de clister	
I Actualmente, controla a função urinária 2☐ Controla bem esta função ou está cateterizado e substitui os sacos 1☐ Perde urina acidentalmente 0☐ Não controla a urina ou está cateterizado e precisa de alguém para substituir os sacos	
J Actualmente, consegue ir à casa de banho 2☐ Não precisa de qualquer ajuda para ir à casa de banho 1☐ Precisa de ajuda, mas consegue fazer algumas coisa sozinho 0☐ Não consegue ir à casa de banho sozinho	
PONTUAÇÃO FINAL	

Appendix IX - Lawton & Brody Instrumental Activities of Daily Living Scale

Escala de Lawton y Brody	Pontuação
1 Capacidade para usar o telefone: 3☐ Utiliza o telefone por própria iniciativa; procura e marca números. 2☐ É capaz de marcar alguns números familiares 1☐ Atende o telefone mas não marca números 0☐ Não é capaz de usar o telefone	
2 Fazer compras: 3☐ Realiza sozinho(a) todas as compras necessárias 2☐ Realiza sozinho(a) as compras pequenas 1☐ Necessita ser acompanhado(a) para fazer qualquer compra 0☐ Totalmente incapaz de ir ás compras	
3 Preparação da comida: 3☐ Organiza, prepara e serve adequadamente as refeições sozinha 2☐ Prepara adequadamente as refeições se os ingredientes forem fornecidos 1☐ Prepara, aquece e serve as refeições, mas não mantém uma dieta adequada. 0☐ Necessita que lhe preparem e sirvam as refeições	
4 Cuidado com a casa: 4☐ Mantém a casa arrumada, sozinha ou com ajuda ocasional (para trabalhos pesados) 3☐ Realiza tarefas diárias ligeiras, como lavar a louça ou fazer a cama 2☐ Realiza tarefas diárias ligeiras, mas não mantém um nível adequado de limpeza 1☐ Necessita de ajuda em todas as tarefas da lida da casa 0☐ Não participa em nenhuma tarefa doméstica.	
5 Lavar a roupa: 2☐ Lava sozinho(a) toda a sua roupa 1☐ Lava sozinho(a) apenas peças pequenas 0☐ Toda a lavagem de roupa tem de ser realizada por outra pessoa	
6 Usar os meios de transporte: 4☐ Viaja sozinho(a) em transportes públicos ou conduz o seu próprio carro 3☐ É capaz de apanhar um táxi, mas não usa outro meio de transporte 2☐ Viaja em transportes públicos quando acompanhada por alguém 1☐ Só utiliza o táxi ou automóvel com ajuda de outros 0☐ Não viaja	
7 Responsabilidade com a sua medicação: 2☐ É responsável por tomar a sua medicação nas doses correctas e à hora certa 1☐ Toma a sua medicação se lhe for preparada (doses separadas) previamente 0☐ Não é capaz de se responsabilizar pela toma da medicação	
8 Capacidade para tratar dos seus assuntos económicos: 2☐ Gere os seus assuntos financeiros sozinho(a) (cheques, paga a renda, contas bancárias) 1☐ Gere as compras do dia-a-dia, mas necessita de ajuda nas grandes compras, no banco... .. 0☐ Incapaz de gerir o dinheiro	
PONTUAÇÃO FINAL	

Tipo de :Preenchimento

1☐ Auto-preenchimenro
2☐ Entrevista

Tempo de preenchimento: _______________ minutos

Muito obrigado pela sua colaboração e disponibilidade

Appendix X - International Physical Activity Questionnaire (IPAQ) – Short version

QA	ID							

QUESTIONÁRIO INTERNACIONAL DE ACTIVIDADE FÍSICA (IPAQ)

Estamos interessados em conhecer os diferentes tipos de actividade física, que as pessoas fazem no seu quotidiano. Este questionário faz parte de um estudo alargado realizado em vários países. As suas respostas vão-nos ajudar a conhecer o nosso nível de actividade física, quando comparado com o de pessoas de outros países.

As questões que lhe vou colocar, referem-se à semana imediatamente anterior, considerando o tempo em que esteve fisicamente activo/a. Por favor, responda a todas as questões, mesmo que não se considere uma pessoa fisicamente activa. Vou colocar-lhe questões sobre as actividades desenvolvidas na sua actividade profissional e nas suas deslocações, sobre as actividades referentes aos trabalhos domésticos e às actividades que efectuou no seu tempo livre para recreação ou prática de exercício físico / desporto.

Ao responder às seguintes questões considere o seguinte:

Actividades físicas vigorosas *referem-se a actividades que requerem um esforço físico intenso que fazem ficar com a respiração ofegante.*
Actividades físicas moderadas *referem-se a actividades que requerem esforço físico moderado e tornam a respiração um pouco mais forte que o normal.*

*Ao responder às questões considere apenas as actividades físicas que realize durante pelo menos **10 minutos seguidos**.*

Q.1 Diga-me por favor, nos últimos 7 dias, em quantos dias fez actividades físicas vigorosas, como por exemplo, levantar objectos pesados, cavar, ginástica aeróbica, nadar, jogar futebol, andar de bicicleta a um ritmo rápido?

☐ **Dias**

Q.2 Nos dias em que pratica actividades físicas vigorosas, quanto tempo em média dedica normalmente a essas actividades?

☐☐ **Horas** ☐☐ **Minutos**

Q.3 Diga-me por favor, nos últimos 7 dias, em quantos dias fez actividades físicas moderadas como por exemplo, carregar objectos leves, caçar, trabalhos de carpintaria, andar de bicicleta a um ritmo normal ou ténis de pares? Por favor não inclua o "andar ".

☐ **Dias**

Q.4 Nos dias em que faz actividades físicas moderadas, quanto tempo em média dedica normalmente a essas actividades?

☐☐ **Horas** ☐☐ **Minutos**

Q.5 Diga-me por favor, nos últimos 7 dias, em quantos dias andou pelo menos 10 minutos seguidos?

☐ **Dias**

Q.6 Quanto tempo no total, despendeu num desses dias, a andar/caminhar?

☐☐ **Horas** ☐☐ **Minutos**

Q.7 Diga-me por favor, num dia normal quanto tempo passa sentado? Isto pode incluir o tempo que passa a uma secretária, a visitar amigos, a ler, a estudar ou a ver televisão.

☐☐ **Horas** ☐☐ **Minutos**

1

Appendix XI – Assessment Report delivered to participants

Relatório de Avaliação

Movement Older Adults Biomechanical Analysis

Identificação			
Nome			
Idade			
Nome do avaliador		Data da avaliação	

Avaliação de Sinais Vitais e Composição Corporal	
Frequência Cardíaca	
Tensão Arterial	
Peso	
Massa Muscular (Kg)	
Massa óssea (Kg)	
Percentagem de Massa gorda	
Perímetro Abdominal (m)	
Perímetro da Anca (m)	
Índice de massa corporal	

Avaliação de Atividades de Vida Diária	
Pontuação Atividades Básicas de Vida Diária	
Pontuação Atividades Instrumentais de Vida Diária	
Pontuação da avaliação da capacidade cognitiva	
Pontuação do Nível de atividade Física	

Pontuação da performance nos testes funcionais	
10 metros marcha (s)	
Teste sentar e levantar 5 vezes (s)	
Timed up and Go (s)	
Equilíbrio em uma perna (s)	

Projeto financiado através da bolsa 2020.05356.BD e do financiamento de unidades de I&D (UIDB/05210/2020), Fundação para a Ciência e Tecnologia (FCT), Portugal e União Europeia

Appendix XII - Supplementary Materials of Study I

Supplemental Information

Search strategy

This protocol amendment was written a priori, executed before final study selection and data extraction, and followed throughout the review process.

Table 1: Search strategy of Study I.

Overview	
Databases	Pubmed Scopus Web of Science CINAHL Embase Subject headings have been customized for each database. Duplicates between databases were removed in EndNote™(Clarivate™), v 20, software.
Search date	April 8th, 2021
Study Design	Observational studies, including cohort and cross-sectional studies
Limits	No date limit (included all studies until April 8th, 2021) Limit study design to observational studies, including cohort and cross-sectional studies and excluding meta-analyses, reviews, randomized and non-randomized controlled trials, case reports, pilot studies, technical notes, letters, editorials or studies published as conference proceedings No language limits was added to search strategy, but studies with languages other than English, French, Spanish and Portuguese were excluded in title and abstract analysis

Search Strategy	
Population	Community-dwelling older adults
Exposure	Modifications according aging process
Outcome	Disability measures
Study Design	Observational studies, including cohort and cross-sectional studies

Syntax Guide	
MeSH	Medical Subject Heading
exp	Explode a subject heading
*	After a word, a truncation symbol (wildcard) to retrieve plurals or varying endings
#	Truncation symbol for one character
TS	Title and abstract

Pubmed

("aged"[MeSH Terms] OR "aged"[Title/Abstract] OR "elder*"[Title/Abstract] OR "aged, 80 and over"[MeSH Terms] OR "older adult*"[Title/Abstract] OR "older person*"[Title/Abstract] OR "centenarian*"[Title/Abstract] OR "nonagenarian*"[Title/Abstract] OR "octogenarian*"[Title/Abstract])

AND

("independent living"[MeSH Terms] OR "independent living"[Title/Abstract] OR "community dwelling"[Title/Abstract] OR "community-dwellers"[Title/Abstract] OR "community living"[Title/Abstract] OR "aging in place"[Title/Abstract])

AND

("aging"[MeSH Terms] OR "aging"[Title/Abstract] OR "ageing"[Title/Abstract] OR "senescence"[Title/Abstract] OR "Biological Aging"[Title/Abstract])

AND

("Disability Evaluation"[MeSH Terms] OR "Disability Evaluation"[Title/Abstract] OR "disabilit*"[Title/Abstract] OR "disabled persons"[MeSH Terms] OR "disabled person*"[Title/Abstract] OR "handicap*"[Title/Abstract] OR "Functional Status"[MeSH Terms] OR "Functional Status"[Title/Abstract] OR "Functional Independence"[Title/Abstract] OR "functional capacity"[Title/Abstract] OR "functional performance"[Title/Abstract] OR "functional assessment*"[Title/Abstract] OR "physical assessment*"[Title/Abstract] OR "health status"[MeSH Terms] OR “health status”[Title/Abstract] OR "health status indicators"[MeSH Terms] OR "Population Health"[MeSH Terms] OR "Population Health"[Title/Abstract] OR "geriatric assessment"[MeSH Terms] OR "geriatric assessment*"[Title/Abstract])

AND

("observational study"[Publication Type] OR "observational studies as topic"[MeSH Terms] OR "observational stud*"[Title/Abstract] OR "comparative study"[Publication Type] OR "validation study"[Publication Type] OR "Validation Studies as Topic" [MeSH Terms] OR "validation stud*"[Title/Abstract] OR "Journal Article"[Publication Type] OR "cross sectional studies"[MeSH Terms] OR "cross sectional"[Title/Abstract] OR "cross sectional stud*"[Title/Abstract] OR "cohort studies"[MeSH Terms] OR "cohort"[Title/Abstract] OR "cohort stud*"[Title/Abstract] OR "Prospective studies"[MeSH Terms] OR "prospective stud*"[Title/Abstract] OR "Retrospective studies"[MeSH Terms] OR "retrospective stud*"[Title/Abstract] OR "longitudinal studies"[MeSH Terms] OR "Surveys and questionnaires"[MeSH Terms] OR "Feasibility studies"[MeSH Terms] OR "feasibility stud*"[Title/Abstract])

NOT

("randomized controlled trial"[Publication Type] OR "randomized controlled trials as topic"[MeSH Terms] OR "randomized controlled trial"[Title/Abstract] OR "clinical trial"[Publication Type] OR "clinical trial"[Title/Abstract] OR "controlled clinical trial"[Publication Type] OR "controlled clinical trials as topic"[MeSH Terms] OR "controlled clinical trial"[Title/Abstract] OR "Comment"[Publication Type] OR "Letter"[Publication Type] OR "correspondence as topic"[MeSH Terms] OR "Editorial"[Publication Type] OR "Review"[Publication Type] OR "review literature as topic"[MeSH Terms] OR "Systematic review"[Publication Type] OR "Systematic reviews as topic"[MeSH Terms] OR "systematic review"[Title/Abstract] OR "Meta-Analysis"[Publication Type] OR "Meta analysis as Topic"[MeSH Terms] OR "Meta analysis"[Title/Abstract] OR "Meta-analysis as Topic"[MeSH Terms] OR "Guideline"[Publication Type] OR "Practice Guideline"[Publication Type] OR "Practice Guidelines as Topic"[MeSH Terms])

SCOPUS

TITLE-ABS-KEY("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*")

AND

TITLE-ABS-KEY("independent living" OR "community dwelling" OR "community-dwellers" OR "community living" OR "aging in place")

AND

TITLE-ABS-KEY("aging" OR "ageing" OR "senescence" OR "Biological Aging")

AND

TITLE-ABS-KEY("Disability Evaluation" OR "disabilit*" OR "disabled person*" OR "handicap*" OR "Functional Status" OR "Functional Independence" OR "functional capacity" OR "functional performance" OR "functional assessment*" OR "physical assessment*" OR "health status" OR "Population Health" OR "geriatric assessment*")

AND

(TITLE-ABS-KEY ("observational stud*" OR "cross sectional" OR "cross sectional stud*" OR "cohort" OR "cohort stud*" OR "Prospective stud*" OR "Retrospective stud*" OR "feasibility stud*" OR "validation stud*")

AND NOT

(TITLE-ABS-KEY ("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis"))

Web of Science

TS=("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*")

AND

TS=("independent living" OR "community dwelling" OR "community-dwellers" OR "community living" OR "aging in place")

AND

TS=("aging" OR "ageing" OR "senescence" OR "Biological Aging")

AND

TS=("Disability Evaluation" OR "disabilit*" OR "disabled person*" OR "handicap*" OR "Functional Status" OR "Functional Independence" OR "functional capacity" OR "functional performance" OR "functional assessment*" OR "physical assessment*" OR "health status" OR "Population Health" OR "geriatric assessment*")

AND TS=("observational stud*" OR "cross-sectional" OR "cross sectional stud*" OR "cohort" OR "cohort stud*" OR "Prospective stud*" OR "Retrospective stud*" OR "feasibility stud*" OR "validation stud*")
NOT TS=("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis")

CINHAL

S1 (MH "aged+") OR (MH "aged, 80 and over+") OR (TI ("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*") OR AB ("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*"))
AND
S2 (MH "Community living+") OR (TI ("independent living" OR "community-dwelling" OR "community-dwellers" OR "community living" OR "aging in place") OR AB (“independent living" OR "community-dwelling" OR "community-dwellers" OR "community living" OR "aging in place"))
S3 S1 AND S2
AND
S4 (MH "aging+") OR (TI ("aging" OR "ageing" OR "senescence" OR "Biological aging") OR AB ("aging" OR "ageing" OR "senescence" OR "Biological aging"))
AND
S5 (MH "Disability Evaluation+") OR (MH "Functional Assessment+") OR (MH "Geriatric Assessment+") OR (MH "Functional Status+") OR (MH "Health Status+") OR (MH "Health Status Indicators+") OR (MH "Population health+") OR (TI ("Disability Evaluation" OR "disabilit*" OR "disabled person* OR "handicap*" OR "Functional Status" OR "Functional Independence" OR "functional capacity" OR "functional performance" OR "functional assessment*" OR "physical assessment*" OR "health status" OR "Population Health" OR "geriatric assessment*") OR AB ("Disability Evaluation" OR "disabilit*" OR "disabled person* OR "handicap*" OR "Functional Status" OR "Functional Independence" OR "functional capacity" OR "functional performance" OR "functional assessment*" OR "physical assessment*" OR "health status" OR "Population Health" OR "geriatric assessment*"))

S6 S3 AND S4 AND S5

S7 (PT “Journal Article”) OR (PT “Research”) OR (PT “Research Instrument”) OR (MH “Nonexperimental Studies”) OR (MH” Prospective Studies”) OR (MH “Concurrent Prospective Studies”) OR (MH “Nonparticipant Observation”) OR (MH “Cross Sectional Studies” OR (MH “Observational methods”) OR (MH “Retrospective panel studies”) OR (MH “Validation Studies”) OR (MH “Questionnaires”) OR (MH “Outcomes research”)) OR (TI ("observational stud*" OR "cross sectional" OR "cross sectional stud*" OR "cohort" OR "cohort stud*" OR "Prospective stud*" OR "Retrospective stud*" OR "feasibility stud*" OR "validation stud*") OR AB ("observational stud*" OR "cross sectional" OR "cross sectional stud*" OR "cohort" OR "cohort stud*" OR "Prospective stud*" OR "Retrospective stud*" OR "feasibility stud*" OR "validation stud*"))

NOT

(PT “Randomized Controlled Trials”) OR (PT “Clinical Trial”) OR (PT “Commentary”) OR (PT “Editorial”) OR (PT “Letter”) OR (PT “Meta Analysis”) OR (PT “Practice Guidelines”) OR (PT “Review”) OR (PT “Systematic Review”) OR (MH “Randomized Controlled Trials”) OR (MH “Clinical Trials”) OR (MH “Meta Analysis”) (MH “Scoping Review”) OR (MH “Systematic Review”) OR (MH “Literature Review”) OR MH (“Practice Guidelines”) OR (TI ("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis") OR AB ("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis"))

EMBASE

('aged'/exp OR 'very elderly'/exp)

OR

('aged':ab,ti OR 'elder*':ab,ti OR 'older adult*':ab,ti OR 'older person*':ab,ti OR 'centenarian*':ab,ti OR 'nonagenarian*':ab,ti OR 'octogenarian*':ab,ti)

AND

('independent living/exp' OR 'community living'/exp OR 'community dwelling person'/exp)

OR

('independent living':ab,ti OR 'community-dwelling':ab,ti OR 'community-dwellers':ab,ti OR 'community living':ab,ti OR 'aging in place':ab,ti)

AND

('aging'/exp)

OR

('aging':ab,ti OR 'ageing':ab,ti OR 'senescence':ab,ti OR 'Biological aging':ab,ti)

AND

('disability/exp' OR 'disabled person'/exp OR 'functional status'/exp OR 'health status/exp' OR 'health status indicator'/exp OR 'population health'/exp OR 'functional assessment/exp' OR 'geriatric assessment'/exp OR 'physical disability'/exp)

OR

('disabilit*':ab,ti OR 'disability evaluation':ab,ti OR 'disabled person*':ab,ti OR 'handicap*':ab,ti OR 'functional status':ab,ti OR 'functional independence':ab,ti OR 'functional capacity':ab,ti OR 'functional performance':ab,ti OR 'functional assessment*':ab,ti OR 'physical assessment*':ab,ti OR 'health status*':ab,ti OR 'population health':ab,ti OR 'geriatric assessment':ab,ti)

AND

('cohort analysis'/de OR 'comparative study'/de OR 'cross sectional study'/de OR 'diagnostic test accuracy study'/de OR 'feasibility study'/de OR 'human'/de OR 'longitudinal study'/de OR 'observational study'/de OR 'outcomes research'/de OR 'prospective study'/de OR 'questionnaire'/de OR 'retrospective study'/de OR 'validation study'/de) OR ('Prospective Study'/exp OR 'Cross sectional study'/exp OR 'Observational study'/exp OR 'Cohort analysis'/exp OR 'Retrospective study'/exp OR 'Validation Study'/exp OR 'Longitudinal study'/exp OR 'Questionnaire'/exp OR 'Outcomes research'/exp OR 'Feasibility study'/exp OR 'Diagnostic test accuracy'/exp)

OR

('observational stud*':ab,ti OR 'cross sectional':ab,ti OR 'cross sectional stud*':ab,ti OR 'cohort':ab,ti OR 'cohort stud*':ab,ti OR 'cohort analysis':ab,ti OR 'prospective stud*':ab,ti OR 'retrospective stud*':ab,ti OR 'feasibility stud*':ab,ti OR 'validation stud*':ab,ti)

NOT

'clinical article'/de OR 'clinical trial'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'human experiment'/de OR 'human tissue'/de OR 'interview'/de OR 'major clinical study'/de OR 'meta analysis'/de OR 'model'/de OR 'nonhuman'/de OR 'practice guideline'/de OR 'randomized controlled trial'/de OR 'randomized controlled trial topic'/de OR 'semi structured interview'/de OR 'systematic review'/de OR 'telephone interview'/de OR 'randomized controlled trial'/exp OR 'controlled study'/exp OR 'clinical trial'/exp OR 'letter'/exp OR 'editorial'/exp OR 'review'/exp OR 'meta analysis'/exp OR 'practice guideline'/exp OR 'randomized controlled trial':ab,ti OR 'controlled clinical trial':ab,ti OR 'clinical trial':ab,ti OR 'systematic review':ab,ti OR 'meta analysis':ab,ti

Assessment of methodologic quality

Table 2: Modified version of Downs and Black adapted to observational studies (Rollo et al., 2020).

Reporting
1. Is the hypothesis/aim/objective of the study clearly described?
2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?
3. Are the characteristics of the participants included in the study clearly described?
4. Is the study design clearly described (i.e., cross-sectional vs. prospective; if prospective, time of assessments)?
5. When appropriate, were principal covariates clearly described?
6. Are the main findings of the study clearly described?
7. Does the study provide estimates of the random variability in the data for the main outcomes?
8. Have the characteristics of participants lost to follow-up and/or with missing data been described?
9. Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes except where the probability value is <0.001?
External validity
10. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
11. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
Internal validity bias
12. If any of the results of the study were based on "data dredging", was this made clear?
13. Were the exposure(s) of interest measured prior to the outcome(s) being measured?
14. Were the statistical tests used to assess the main outcomes appropriate?
15. Were the main exposure and outcome measures used accurate (valid and reliable)?
Internal validity confounding (selection bias)
16. When appropriate, was there adequate adjustment for confounding (i.e., covariates) in the analyses from which the main findings were drawn?
17. Were losses of participants to follow-up and/or with missing data taken into account?
Power
18. Did the study report a formal power calculation for determining the association between exposure(s) and outcome(s) variables?
19. Was the sample size used for analyses reflective of the power calculation?

Excluded Studies after full text analysis

The majority of the studies were excluded since included in the sample participants with pathology highly associated to disability (Anstey & Smith, 1999; Atkinson et al., 2005; Buchman et al., 2014; Burns et al., 2017; Busch et al., 2015; Christensen et al., 1994; Connolly et al., 2017; Dale et al., 2018; Doyev et al., 2021; Fabre et al., 2007; Ford et al., 2000; Forrest et al., 2007; Fujiwara et al., 2008; García-Esquinas et al., 2019; Gell et al., 2015; Gill et al., 2008; Han et al., 2013; Jang et al., 2003; Jung et al., 2018; Kabayama et al., 2018; Kim et al., 2019; S. Kim et al., 2020; Mueller-Schotte et al., 2019; Murayama et al., 2020; Nüesch et al., 2015; Piguet et al., 2002; Piguet et al., 2003; Pinto & Neri, 2013; Rodgers et al., 2017; Schmitt et al., 1996; Siordia, 2015; Smagula et al., 2017; Steffen et al., 2002; Stineman et al., 2013; Strotmeyer et al., 2018; Tassino et al., 2009; Thaler-Kall et al., 2015; Tiedemann et al., 2005; Trevisan et al., 2020; Ward et al., 2014; Wu et al., 1999; Xue et al., 2010; Xue et al., 2015; Yeh & Liu, 2003; Yip et al., 2001), 11 because the sample included participants under the age of 60 years (Brady et al., 2005; Castellanos-Perilla et al., 2020; Eslinger et al., 2003; Goble & Baweja, 2018; Lee et al., 2017; Li et al., 2015; Manckoundia et al., 2008; Paúl et al., 2010; Saito et al., 2019; Smith et al., 2016; Tang et al., 2002), 8 a sample with institutionalized patients (Bravell & Stig Berg, 2008; Cohen-Mansfield et al., 2013; Fastame & Cavallini, 2011; Ferraro et al., 2021; Freeman et al., 2010; Mustafaoğlu et al., 2015; Shubert et al., 2006; Vellas et al., 1997), and 3 including households (Prince et al., 2018; The & Assanangkornchai, 2020; Willie-Tyndale et al., 2016). 16 studies were excluded because the ageing process was not the tested exposure, or its effect could not be isolated, or the statistical descriptive values were not provided (Baloh et al., 1998; Chen et al., 2015; Inzitari et al., 2008; Madeira et al., 2020; McAuliffe et al., 2019; Nikula et al., 2003; Purath et al., 2009; Riebe et al., 2009; Rudberg et al., 1996; Sallinen et al., 2011; Simonsick et al., 1998; Stessman et al., 2017; Whelan, 2009; Williams et al., 2007; Woo et al., 2001; Yu et al., 2016). Lacking evaluating of disability, or isolated measures of disability, or disability measure not reported was the criteria to exclude 4 studies (Branch et al., 1989; Hébert et al., 1997; Luthy et al., 2015; Montero-Odasso et al., 2020).

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Supplementary tables

Table 3: Characterization and summary of studies included in the review with classification of "Good" in Downs and Black scale, listed by decreasing order of quality score (for those with same score alphabetic order was used). (Supplementary table S1)

Notes: AG – age group, ANOVA - Analysis of variance; M±SD – Mean plus Standard Deviation; NR – non reported; NS – non significant; * - study design non reported in the respective study, and thus classified by the reviewers; † - indicators with significative change or association with age.

ID	**Study Design** (Follow-up time) **Sample Size**	**Age** M±SD [range] % female	**Indicators** Objective & Self-reported	**Instrument**	**Main statistical strategy used to assess the influence of age**	**Significative change/ association with age**

Desrosiers et al., 2009 [46] (Canada)	Cross-sectional n=350 AG (65–69) n=70 (70–74) n=70 (75–79) n=70 (80–84) n=70 (85+) n=70	AG (65–69) 67.2 ± 1.5 (70–74) 71.9 ± 1.3 (75–79) 76.9 ± 1.4 (80–84) 81.9 ± 1.5 (85+) 87.9 ± 2.4 50%	*Self-reported measure:* 1. Social participation assessed by questionnaire	1. Assessment of Life Habits (LIFE-H)	ANOVA of the LIFE-H scores were performed with the five age groups. Bivariate correlations were used to identify statistically significant variables associated with participation. Independent variables, including demographic, health-related and environmental characteristics that were correlated at $p<0.15$ with the participation scores were put in each of the two main models (LIFE-H daily activities subscore and LIFE-H social roles subscore) as well as each domain of the LIFE-H. Ordinal variables with more than two levels were treated as continuous variables.	Daily activities: Nutrition p=0.97; Fitness p=0.06; Personal care **p<0.001†**; Communication **p<0.001†**; Housing **p=0.003†**; Mobility **p<0.001†**; Daily activities subscore **p<0.001†** Social roles: Responsibilities p=0.09; Interpersonal relationships p=0.46; Community life **p<0.001†**; Leisure **p<0.001†**; Social roles subscore p**<0.001†** Total score **p<0.001†** Daily activities Age β=0.02, CumR^2=0.12 **p<0.001†** Personal care Age β=0.01, CumR^2=0.11, **p<0.001†** Communication Age β=0.19, CumR^2=0.06, **p<0.001†** Housing Age β=0.03, CumR^2=0.06, **p<0.001†** Mobility Age β=0.06, CumR^2=0.14, **p<0.001†** Social roles Age β=0.02, CumR^2=0.06, **p<0.001†** Community life Age β=0.04, CumR^2=0.07, **p<0.001†**

Dodge et al., 2008 [47] (Japan)	Cross-sectional n=303 AG (65–69) n=68 (70–74) n=62 (75–79) n=77 (80–84) n=53 (85+) n=43	76.1 ± 6.9 [65, 96] AG (65–69) 51.5% (70–74) 41.9% (75–79) 55.8% (80–84) 49.1% (85+) 45.2%	*Self-reported measures:* 1. Vision or hearing impairment assessed by questionnaire 2. Instrumental Activities of Daily Living (IADL) disabilities assessed by questionnaire 3. Leisure activities assessed by questionnaire *Objective measures:* 4. Mobility assessed by time to complete Timed up and go test (TUG) 5. Morbidity measured by medication 6. Cognitive function assessed by tests	1. ''what is your visual ability with your visual aid?''; ''what is your hearing ability with your hearing aid?'' 2. Tokyo Metropolitan Institute of Gerontology Index of Competence; questions about telephone use, medication management, and cleaning rooms 3. Leisure activities providing indexes for physical, nonphysical hobbies and social activity. 4. TUG 5. Total number of prescription medications 6.1 MMSE 6.2. Digit Span Forward and Backward from Wechsler Adult Intelligence Scale Revised (WAIS-R) 6.3 Block Designs-5 blocks, even numbers from the WAIS-R Block Design 6.4 Trail-making test A and B	Participants with scores of 2 or 3 were regarded as having vision and/or hearing impairment. Age group differences in the different outcomes using Pearson Chi square and ANOVA. Age group differences in each of the three indexes were examined by t test (nonphysical and social activity indexes) and Wilcoxon rank sum nonparametric test (physical activity index, due to skewed distribution), comparing the youngest age group (65–75 years) with each of two other age groups (75–84 years and 85 years or older).	Pearson chi-square statistics % With either vision or hearing impairment **p<0.001†** IADL disabilities, % None **p<0.001†** % with 21 MMSE **p=0.001†** ANOVA TUG **p<.001†** Total No. of prescription medication **p<0.001†** WAIS-R Digit Span Forward NS WAIS-R Digit Span Backward **p=0.005†** WAIS-R Block Design–5 block designs **p<0.001†** Trail-Making A: connections per second **p<0.001†** Trail-Making B: connections per second **p<0.001†** Nonphysical Activity Index (t test) (65 - 75)-(75-85) p=0,19; (85+)-(65 - 75) **p<0.001†** Physical Activity Index (Wilcoxon rank test) (65 - 75) - (75-85) p=0,45; (85+) - (65 - 75) **p=0.04†** Social Activity Index (t test) (65 - 75) - (75-85) p=0,22; (85+) - (65 - 75) **p<0.001†**

Pinheiro et al., 2013 [67] (Brazil)	Cross-sectional n=316	74.2 ± 9 .8 [60, 105] 54.7%	*Objective measures:* 1. Handgrip strength (HG) assessed by dynamometry 2. Strength/ endurance of the lower limbs assessed by time to perform 5 sit-to-stand 3. Mobility/ flexibility assessed by the time to perform a task 4. Locomotion assessed by time to walk a path of 2.44 m 5. Balance assessed by task performance	1. Hydraulic dynamometer (Saehan Corporation SH5001, Korea) 2. Chair stand test (STS) 3. Pick-up-a-pen test (PPT) (movement between bending down and returning to the former position) 4. Walk test (WT) 5. Maintain balance: both feet together, tandem, while standing only on the right/ left leg	The effect of age on motor performance was assessed by the Kruskal-Wallis test 60-69), (70-79), (≥ 80). Chi-square calculations of the age group, sex and categories of test performance (Disabled, Poor, Medium, Good); if any expected frequency was below five, then Fisher's exact test was applied.	Kruskal-Wallis test HG All **p<0.001†**; Men **p<0.001†**; Women **p<0.001†** STS All **p=0.001†**; Men **p<0.001†**; Women **p=0.012†** PPT All **p<0.001†**; Men **p<0.001†**; Women **p<0.001†** WT All **p<0.001†**; Men **p<0.001†**; Women **p<0.001†** Chi-square or Fisher's exact test HG Men **p=0.002†**; Women **p<0.001†** STS Men **p=0.002†**; Women **p=0.009†** PPT Men **p<0.020†**; Women **p=0.001†** WT Men **p<0.020†**; Women **p<0.001†** Balance Men **p<0.001†**; Women **p<0.001†**

Uttl et al., 2001[80] (Canada)	Cross-sectional* n=133 AG 65–69 n=31 70–74 n=41 75–79 n=38 80–95 n=23	[65, 95] 58.6%	*Self-reported measures:* 1. Self-rating about eyesight hearing, and general health *Objective measures:* 2. Cognitive function 3. Sensation 4. Prospective memory (PM) assessed by three brief tasks 5. Retrospective memory (RM) assessed by test 6. Attention assessed by test 7. Semantic fluency assessed by test 8. Cognition assessed by test	1. 1=5 excellent to 5=unable to see, 1=excellent to 5=unable to hear and 1=very good to 5=very poor general health 2. Modified Mini-Mental State examination (MMS) 3. Color Vision Screening Inventory (CVSI) 4. The name task, the letter task, and the check task. 5. Retrospective Memory tests: Buschke 1-3; RAVLT A1-5; RAVLT A6; RAVLT B1 6. Cancel H, Card sorting, Digit symbol 7. Verbal fluency, Animal naming, Picture naming 8. Modified Mini-Mental State (MMS)	Age effects were computed by regression analysis.	MMS F=23.77, **p<0.05†**; CVSI F=0.04, p>0.05; Vision F= 1.40, p>0.05; Hearing F=1.63, p>0.05; Health F=3.13, p=0.079 Tasks PM: Name X^2=14.0, **p=0.001†**; Letter X^2=3.39, p=0.066; Check X^2=5.55, **p=0.019†** Items PM : Name: Pen X^2=9.55, **p<0.05†**; Paper X^2=13.03, **p<0.05†**; Letter: Pen X^2=2.04, p>0.05; Letter X^2=2.53, p>0.05; Envelope X^2=12.21, **p<0.05†**; Check: Pen X^2=4.59, **p<0.05†**; Envelope X^2=11.48, **p<0.05†**; Check X^2=5.16, **p<0.05†** Activities PM: Name: Write X^2=7.58, **p<0.05†**; Letter: Date X^2=5.63, **p<0.05†**; Sign X^2=4.95, **p<0.05†**; Copy name X^2=9.15, **p<0.05†**; Copy street X^2=12.54, **p<0.05†**; Copy city X^2=15.24, **p<0.05†**; Copy postal code X^2=12.90, **p<0.05†**; Check: Date X^2=2.64, p>0.05; Pay to X^2=5.98, **p<0.05†**; Amount X^2=7.84, **p<0.05†**; Amount written X^2=3.75, p>0.05; Sign X^2=2.73, p>0.05; Check in envelop X^2=7.30, **p<0.05†** RM tests: Buschke 1-3 F= 12.32, **p=0.05†**, r^2=0.087; RAVLT A1-5 F=6.26, **p=0.05†**, r^2=0.046; RAVLT A6 F=4.54, **p=0.05†**, r^2=0.034; RAVLT B1 F=7.39, **p=0.05†**, r^2=0.054 Attention tests: Cancel H F= 17.14, **p=0.05†**, r^2=0.117; Card sorting F= 42.20, **p=0.05†**, r^2=0.245; Digit symbol F= 18.68, **p=0.05†**, r^2=0.126 Semantic fluency: Verbal fluency F= 8.04, **p=0.05†**, r^2=0.058; Animal naming F=14.79, **p=0.05†**, r^2=0.102; Picture naming F=26.19, **p=0.05†**, r^2=0.168

Makizako et al., 2017 [60] (Japan)	Cross-sectional n=10 092	73.6 ± 5.6 Male 73.7 ± 5.6 Female 73.6 ± 5.6 52,5%	*Objective measures:* 1. Physical performance assessed by level of grip strength, time to five-time-sit-to-stand (FTSS), and walking speed 2. Body composition assessed by values of Body weight, Fat mass and Appendicular muscle mass	1. Smedley-type handheld dynamometer (GRIP-D; Takei Ltd, Niigata, Japan), FTSS test and walking speed at 2 meter comfortable pace 2. Bioelectrical impedance analyzer (MC-980A; Tanita, Tokyo, Japan)	Pearson's correlation coefficients were calculated to assess the simple correlations of physical performance measures and body composition parameters with age. To compare the differences in the age-dependent changes among various measures, T-scores were calculated by using the equation: T score= 50+10†(participant's value - population mean)/ population standard deviation. Then, the T-scores for each measure in the 65–69 year age group were set as references (i.e. T-score = 50), and the cumulative mean T-score change for each age group was calculated. For the T-score curve for the FTSS, the curve was inverted (decreasing with advancing age). For the evaluation of the slope decline in age-associated changes among the indicators, authors used linear regression.	Pearson's correlation coefficients Male Grip strength, kg r=-0.44, **p<0.01†** FTSS, s r=0.27, **p<0.01†** Walking speed, m/s r=-0.37, **p<0.01†** Body weight, kg r= -0.23, **p<0.01†** Fat mass, kg r=-0.02, p≥0.01 Appendicular muscle mass, kg r=-0.32, **p<0.01†** Female Grip strength, kg r=-0.36, **p<0.01†** FTSS, s r=0.33, **p<0.01†** Walking speed, m/s r=-0.48, **p<0.01†** Body weight, kg r= -0.17, **p<0.01†** Fat mass, kg r=-0.05, **p<0.01†** Appendicular muscle mass, kg r=-0.32, **p<0.01†** T-score results confirm that all physical performance measures, BMI and Appendicular muscle mass worsened with advancing age.

Papadakis et al., 1995 [66] (USA)	Cross-sectional n=104	75.5±4.9 [70, 94] 0%	*Objective measures:* 1. Muscle strength assessed by Peak torque of knee flexion and extension at joint speeds of 90, 120, and 180 degrees per second (dps) and Grip strength 2. Physical Performance assessed by time to complete different tasks 3. Body composition assessed by lean tissue mass and fat mass 4. Cognitive function assessed by three tests	1. Isokinetic dynamometer (Cybex 340, Lumex Corp., Bay Shore, NY) and grip dynamometer (Smedley Grip Dynamometer, JA Preston, Jackson, MI) 2. Physical Performance Test (write a prescribed sentence, transfer kidney beans using a teaspoon, place a heavy book on a shelf, remove a jacket, pick up a penny from the floor, turn 360 degrees, walk a 50-foot walk test course, and climb stairs to determine speed and number of flights climbed before the subject fatigued) 3. Dual-energy X-ray absorptiometry (DEXA) (Lunar DPX-Plus, Madison, WI) 4. Mini-Mental State Examination, Trails B, and the Digit Symbol Substitution	Multiple linear regression for each variable including age and IGF-1 as independent variables	Muscle strength Knee extension: Peak torque 120 dps (ft-lbs) β=-1.8 **p=0.0001†**, Model r^2=0.174 Knee flexion: Peak torque 120 dps (ft-lbs) β=-0.87, **p=0.004†**, Model r^2=0.1 05 Handgrip (kg) β=-0.65, **p=0.0002†**, Model r^2=0.19 Body composition Percent lean tissue mass β=-0.10 p=0.45, Model r^2=0.01 Percent fat mass β=- 123.9 p=0.59, Model r^2=0.008 Physical Performance Test β=-0.27, **p=0.0001†**, Model r2=0.247 Cognitive function Trails B score β= 3.73, **p=0.0001†**, Model r^2= 0.257 Mini-Mental State Exam β=-0.09, **p=0.005†**, Model r^2=0.123 Digit Symbol Substitution test β t=-0.85 **p=0.0003†**, Model r^2=0.210

Romero-Ortuno et al., 2009 [71] (Ireland)	Cross-sectional n=355 AG 60–69 n = 133 70–79 n = 153 80–89 n = 69	72.7 ± 7.2 AG [60-69] 65.3 ± 2.6 70-79 74.2 ± 2.9 [80-89] 83.4 ± 2.8 67.0%	*Objective measures:* 1. Preferred walking speed in m/s	1. GAITRite™ walkway system (CIR Systems, Inc., 60 Garlor Drive, Havertown, PA 19083)	Simple linear regression was conducted to investigate if age predicts walking speed Backwards multiple linear regression was used to investigate the extent to which age was an independent predictor of walking speed in the presence of other confounders	Linear regression (with 95% confidence interval for the mean) between age and observed walking speed $F(1, 353) = 108.48$, $R^2=0.235$, **p<0.001†** Backwards multiple linear regression Age (along with other variables)$F(4, 329) = 156.23$, $R^2=0.651$, **p=0.001†**

Tomsone et al., 2013 [78] (Germany, Latvia and Sweden)	Cross-sectional n=1098 Sub-samples German n=419 Latvian n=292 Swedish n=387	Germany and Sweden sample [80, 89] Latvia sample [75, 84]	*Self-reported/ Objective measures:* 1. ADL independence/dependence assessed by questionnaire	1. ADL Staircase (combination of interview and observation)	For each of the three national samples differences between the two ADL groups were tested by means of Mann–Whitney's U test for age	Differences between age of ADL groups (dependent/independent) German sample **p<0.0005†** Latvian sample **p<0.0005†** Swedish sample **p<0.0005†**
Turner et al., 2016 [79] (USA)	Cross-sectional n=943	80 ± 7.8 76%	*Self-reported measures:* 1. Sleep quality, sleep apnea assessed by questionnaire	1. 32-item Questionnaire developed by the authors to assess sleep quality and determine the occurrence of sleep apnea and REM behavior disorder, using selected questions from the Pittsburgh Sleep Quality Index, the Berlin Questionnaire, and the Mayo Sleep Questionnaire	Chi-square tests, t-tests and one-way ANOVAs to compare the mean sleep scores across different demographic subgroups (Mean differences for one-way ANOVAs are based on Tukey-Kramer post hoc analysis. Chi-square employed for Sleep apnea risk)	Sleep quality score F3939=2.96, **p=0.031†** Sleep apnea risk score X^2=8.41, **p=0.015†**

Adachi et al., 2015 [33] (Japan)	Cross-sectional n=149	74.0 ± 4.0 51%	*Objective measures:* 1. Endurance assessed through walked distance	1. Shuttle walking test (SWT)	Comparison of age between higher and lower level of SWT, according t-test. Analysis of factors associated with the SWT results using a stepwise multivariate logistic regression model, assigning the high SWT results group as a dependent variable and age as explanatory variable	Female **p<0.001†** Male **p=0.002†** Female (Odds Ratio) OR=0.69, Confidence interval 95% CI=0.57–0.82 **p<0.001†** Male p>0.05
Moreira et al., 2016 [62] (Brazil)	Longitudinal Study (2 years) n=103	76.3 ± 5.95 [67, 92] 58.2%	*Self-reported measures:* 1. Activities of daily living (ADL) 2. Instrumental activities of daily living (IADL)	1. Katz Index of ADL 2. Instrumental activities of daily living by Lawton & Brody, 1969	If individuals gave an affirmative response to at least one of the ADL and IADL questions were defined as presenting difficulties. Age comparison between groups (with and without functional decline) were analyzed by Student t-test. Multiple logistic regression model was used considering impairment of ADL and IADL as variable response, and several independent variables as age, using a stepwise variable selection method.	Individuals in 2008 that developed or not ADL decline in 2010 ADL decline **p=0.04†** Study sample in 2008 that developed or not IADL decline in 2010 IADL decline **p=0.001†** Multiple logistic regression of promoting factors for decline. IADL Age OR 1.12, IC95% 1.02–1.23, **p=0.02†** ADL Age NS
Nakagawa et al., 2017 [63] (Brazil)	Cross-sectional n=202	Female 70.2 ± 5.6 Male 71.1 ± 6.9 57.9%	*Objective measures:* 1. Functional balance assessed by activity performance scale *Self-reported measures:* 2. Functional independence in daily life assessed by scale	1. Berg Balance Scale (BBS) 2. Barthel Index (BI)	Comparisons between the age groups (60-69), (70-79), (≥ 80) were made using oneway ANOVA, with Dunn's post-test. The effect of independent variables on the dependent variable (Berg or Barthel), was calculated by a multiple linear regression model, constructed by means of the Enter method (forced input). R^2 was analyzed to ascertain the coefficient of determination of the percentage variation explained by the model.	Comparisons between age groups BBS p=0.000† Dunn's post-test (60-69) vs (70-79), **p<0.01†** (60-69) vs (≥ 80), **p<0.001†** (70-79) vs (≥ 80), **p<0.001†** BI p=0.205 Multiple linear regression BBS: Model R^2=0.369, Age β(95% CI)=-0.344 (-0.424, -0.265), **p=0.0001†** BI: Model R^2=0.122, Age β(95% CI)=--0.086 (-0.141, -0.030), **p=0.003†**

Sarvestan et al., 2021 [73] (Czech Republic)	Cross-sectional* n=27	69.1±5.7 100%	*Objective measures:* 1. Gait and balance assessed by test 2. Gait speed assessed by test 3. Balance assessed by sway velocity in Anteroposterior (AP), Mediolateral (ML) and Vertical (V) directions in standing position during 30 seconds 4. Strength of Ankle invertors (AIN) and evertors (AEV), Ankle plantar flexors (APF), Ankle dorsi flexors (ADF), Knee flexors (KFL) and extensors (KEX), Hip abductors (HAB) and adductors (HAD), Hip flexors (HFL) and extensors (HEX) assessed by dynamometry	1. Performance Oriented Mobility Assessment (POMA) 2. The six-minute walk (SMW) test 3. AMTI force platform (Model OR6-5, Newton, Watertown, MA, USA; sampling frequency 200 Hz) 4. Iso-Med 2000 Isokinetic dynamometer (D&RFerstl, Hemnau, Germany)	The correlation between age with walking performance variables, functional mobility tests and balance performance was investigated using the Pearson's product-moment correlation coefficient	POMA r=-0.51, **p=0.01†** Average walking speed (m.s-1) r=0.62, **p<0.01†** Sway velocity (mm.s-1) AP r=0.55, **p<0.01†** ML r=0.18, p=0.59 V r=0.54, **p<0.01†** AIN (Nm.kg-1) r=-0.49, **p=0.01†** AEV Nm.kg-1) r=-0.43, **p=0.04†** APF (Nm.kg-1)r=-0.65, **p<0.01†** ADF (Nm.kg-1) r=-0.13, p=0.69 KFL (Nm.kg-1) r=-0.50, **p=0.01†** KEX (Nm.kg-1) r=-0.47, **p=0.03†** HAB Nm.kg-1) r=-0.62, **p<0.01†** HAD (Nm.kg-1) r=-0.37, p=0.10 HFL (Nm.kg-1) r=-0.53, **p<0.01†** HEX (Nm.kg-1) r=-0.57, **p<0.01†**

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Tomita & Burns, 2013 [77] (South Africa)	Cross-sectional n=1429	≥65 62%	*Self-reported measures:* 1. Functional status assessed by the areas, activities of daily living (ADL), instrumental activities of daily living (IADL), and physical functioning and mobility (PFM)	1. ADL: "Please indicate the level of difficulty you have with each activity...in dressing, bathing, eating and toileting by yourself"; IADL: "Please indicate the level of difficulty you have with each activity...in taking a bus, taxi and train by yourself, doing light work in or around the house, managing money, and cooking for yourself"; PFM: "Please indicate the level of difficulty you have with each activity...in climbing a flight of stairs, lifting and carrying heavy objects (e.g. a bag weighing 5 kg), and walking 200–300 meters"	Functional status in ADL, IADL, and PFM was classified as two levels: ‘difficulty’ and ‘dependence’. Differences in the functional status by different age groups were assessed using either t-test or Pearson chi-square statistics, adjusted using the poststratification weight, with the second-order correction method for survey design and eventually converted into F statistics.	Functional status across age groups among 65+ age group ADL difficulty F(1.85, 640.57) = 2.65,p=0.08 IADL difficulty F(1.68, 584.34) = 4.45, **p=0.02†** PFM difficulty F(1.51, 524.81) = 5.45, **p=0.01†** ADL dependence F(1.49, 515.78) = 2.62, p=0.09 ADL dependence (>85+ vs. (65–84) F = 7.10, **p<0.01†** IADL dependence F(1.83, 506.56) = 9.54, **p<0.01†** PFM dependence F(1.57, 433.66) = 7.01, **p<0.01†**

Zunzunegui et al., 2006 [81] (Spain)	Longitudinal Study (6 years) n=1283	≥65 49.4%	*Self-reported measures:* 1. ADL assessed by questionnaire 2. Functional limitations assessed by questionnaire 3. Health status assessed by Self-rated health (SRH)	1. Index of basic physical activities - Nagi 2. No difficulty, slight difficulty, great difficulty and unable to do it in stooping/kneeling, reaching/extending arms, pulling/pushing large objects like chairs, and handling or picking up small objects. These questions were combined into two categories to distinguish those who had great difficulty or were unable to do any of the four activities. 3. "How would you rate your health?"	Logistic regression with fixed effects (i.e., the relation between outcome variable and explanatory variables is the same for every subject). Three series of analysis were carried out separately, to estimate the probability of ADL disability, functional limitations and poor self-rated health.	Logistic regression coefficient to estimate population average estimates of ADL disability prevalence. Age Coefficient=0.123 SD=0.014, p>0.05 Logistic regression coefficient to estimate population average estimates of prevalence of functional limitations. Age Coefficient=0.091, SD=0.007, p>0.05 Logistic regression coefficients to estimate population average estimates of prevalence of poor self-rated health. Age Coefficient=-0.001, SD=0.007, p>0.05

Barberger et al., 1992 [39] (France)	Cross-sectional n=2792	75.0 ± 7.0 59,9%	*Self-reported measures:* 1. Health status assessed by questionnaires of ADL, IADL, Mobility and Global self-perceived health 2. Physical health assessed by the presence of visual or hearing impairments and two symptoms (dyspnea and joint pain) *Objective measure:*	1.1 Katz Index of Independence in ADL 1.2 Lawton And Brody IADL Scale 1.3 Index of Mobility scale (Rosow and Breslau) 1.4 Mobility assessed by a scale: bound to bed, home, neighborhood, district, plain difficulties in using means of transportation, no restriction in mobility 1.5 Global self-perceived: Subjective health: "How would you rate your health status presently: very good? good? fair? bad? very bad?"; Relative health: "In comparison to other people of the same age, do you feel rather: better, the same, or worse?" 2.1 "Do you feel some problems when listening to a conversation in a group or in a noisy environment?" 2.2 "Do you suffer from visual problems that impair activities such as reading or	Associations Between Age and the health measures, test non reported Associations between the subject's age and the six health measures (ADL, IADL, Mobility, Rosow, Subjective Health, Relative Health) were studied. Bivariate analyses were first performed, using t-test for age. A logistic regression was performed for each of the six scales, classifying the subjects into the "dependent" or "independent" group. Odds ratios (ORs) were estimated for a difference of one unit (one year) (Subjects were classified as "dependent" for ADL if they were dependent for at least one of the six activities, for IADL if they were unable to perform one of the five (for men) or eight (for women) tasks of Lawton's scale, for mobility if they were restricted to their bed or their house, for the Rosow-Breslau scale was defined by at least one "No" answer in the three items, for subjective health if they rated themselves in "bad or very bad" health, for relative health those answering they felt "worse" than people of the same age.	Associations Between Age and the health measures Joint pain **p<0.001†** Dyspnea **p<0.001†** Visual impairment **p<0.001†** Hearing impairment **p<0 .001†** MMSE score p>0.05 Associations Between Dependency and Age ADL **p<0.001†** IADL **p<0.001†** Mobility **p<0.001†** Rosow **p<0.001†** Subjective Health **p<0.001†** Relative Health **p<0.05†** Correlations of Being "Dependent" With Age ADL OR= 1.06; **p<0.001†** IADL Male OR= 1.10; **p<0 .001†** IADL Female OR=1.13; **p<0.001†** Mobility OR=1.10; **p<0.001†** Rosow OR=1.13; **p<0.001†** Subjective health OR=0.99; ns Relative health OR=0.95; **p<0.001†**

	3. Mental health assessed by cognitive test	sewing?" even if you are wearing a hearing aid or glasses. 2.3 "Do you feel out of breath in some of the following circumstances: at rest, in performing ADLs, for minor efforts walking at the same pace as other people of the same age, for major efforts climbing more than one flight of stairs, never?" 2.4 "Do you suffer from pain in your joints?" 3. Mini Mental State Exam (MMSE)

Chung et al., 2016 [44] (Hong Kong)	Cross-sectional n=944 AG (65–69) n=248 (70–74) n=224 (75–79) n=251 (80–84) n=221	Male 74.3±5.76 Female 74.3±5.61 55.3%	*Objective measures:* 1. Functional fitness assessed by seven testing items 2. Forearm strength assessed by the highest-rated grip performance 3. Static balance assessed by the time to became unbalanced	1. Senior Fitness Test (SFT) battery: Body mass index (BMI) 30-s arm curl test (AC), 30-s chair stand test (CS), the back scratch test (BS), chair sit-and-reach test (CSR), the 8-foot up-and-go test (UG) and the 2-min step test (Step) 2. Hand grip test (HG) 3. Single leg stance test (SLS)	ANOVA performed to determine the AG effect on each testing parameter for men and women separately. A planned contrast was used to explore the differences between any two adjacent AGs. Because three comparisons were included, the significant p value was adjusted to 0.017. a = difference between (65–69) and (70–74), b = differences between (70–74) and (75–79), c = difference between (75–79) and (80–84)	BMI: Men a; b; c NS; Women a; b; c NS; BS: Men a NS; b; c **p<0.017†**; Women a; b NS; c **p<0.017†** CSR: Men a NS; b; c **p<0.017†**; Women a NS; b; c **p<0.017†** UG: Men a; b; c **p<0.017†**; Women a NS; b; c **p<0.017†** CS: Men a; b; c **p<0.017†**; Women a; b NS; b; c **p<0.017†** AC: Men a; b; c **p<0.017†**; Women a; b; c NS; Step: Men a NS; b; c **p<0.017†**; Women a; b NS; c **p<0.017†** HG Men a NS; b; c **p<0.017†**; Women a; b; c **p<0.017†** SLS eyes open: Men a; b; c **p<0.017†**; Women a; b; c **p<0.017†** SLS eyes closed: Men a; b NS; c **p<0.017†**; Women a; b NS; c **p<0.017†**

Dong et al., 2014 [48] (USA)	Cross-sectional n=3159	72.8±8.3 [60, 105] 58.9%	*Self-reported measures:* 1. Physical function assessed with four measures of ability to perform common daily activities 2. Overall health status (OHS) assessed by question 3. Health changes over the last year (HC) assessed by question *Objective measures:* 4. Physical function assessed with physical performance tests	1.1. Katz Index of activities of daily living (ADL) 1.2. Lawton instrumental ADL (IADL) 1.3 Index of mobility (Rosow and Breslau (ROS)) 1.4. Index of basic physical activities - Nagi 2. “In general, how would you rate your health?” on a four-point scale. 3. “Compared to one year ago, how would you rate your health now?” on a three-point scale. 4.1. Chair stand 4.2. Tandem stand 4.3. 8-foot timed walk	Pearson and Spearmen correlation coefficients were calculated to determine the relationships between age and health-related variables and composite score of each physical function test.	ADL r=0.27, **p<0.001†** IADL r=0.48, **p<0.001†** ADLIADL r=0.48, **p<0.001†** NAGI r=0.38, **p<0.001†** ROS r=0.44, **p<0.001†** OHS r=-0.08, **p<0.001†** HC r=-0.11, **p<0.001†** Chair r=-0.34, **p<0.001†** Tandem r=-0.40, **p<0.001†** Walk r=-0.38, **p<0.001†** PhyP (physical performance tests summary score)r=-0.46, **p<0.001†**

Furuna et al., 1998 [51] (Japan)	Longitudinal Study (4 years) n=517 AG (65–69) n = 252 (70–74) n = 159 (75–79) n = 73 (>80) n = 33	NR 62.5%	*Objective measures:* 1. Muscle Strength assessed by Grip Strength in Kg 2. Balance assessed by the time (seconds) in one-leg Standing with or without vision 3. Walking speeds assessed by velocity (m/s) of walking at preferred and maximum speeds 4. Manual speed assessed by maximum finger-tapping rate (Hz) *Self-reported measures:* 5. Functional capacity assessed by IADL index	1. Dynamometer 2. One-leg Standing with or without vision using the preferred leg 3. Walk test (11 meters) 4. Tapping the middle finger (metal knob) against a stainless-steel plate. The metal knob and the plate formed an electrical circuit. 5.TMIG Index of Competence	To detect longitudinal changes in physical performance, a repeated-measure ANOVA with the age-group and double replication of measurement serving as factors was applied to each physical performance. A logistic multiple regression analysis was performed to predict ability to maintain the level of IADL for next 4 years by the baseline age. IALD was coded as "1" when the total score for Instrumental Self-Maintenance in the TMIG Index of Competence decreased in the 4 year follow-up examination, and "0" if the score maintained or increased. Deterioration of IADL was assumed to be a dependent variable. Age was assumed to be independent variable.	The cross-sectional decline was also evident in all physical performances F>9.1, **p<0.0001†** Significant interaction between age-group and longitudinal change in preferred walking speed F=3.3, **p<0.05†** Logistic regression Analysis IADL Age Wald=14.8, OR 1.10, CI95%=1.05-1.15, **p<0.01†**

Grassi et al., 2020 [53] (Italy, Germany, Spain, Switzerland, UK, Israel)	Cross-sectional n=3142	73.7 ± 5.6 50.7%	*Self-reported measures:* 1. Functioning assessed by questionnaire 2. Self-Health Rated (SHR) assessed by single question	1. World Health Organization Disability Assessment Schedule II (WHODAS-II) 2. How do you rate your overall health in the past 30 days?, a score of 1 corresponding to “very good” and 5 to “very bad”	Linear regressions were used to analyze the effect of four age groups (65–69, 70–74, 75–79, > 80) on the WHODAS-II, its subscales and SHR.	WHODAS II total score **p<0.001†** Mobility **p<0.001†** Household **p<0.001†** Cognitive **p<0.001†** Social p=0.426 Self-care **p<0.001†** Society **p<0.001†** SHR **p<0.05†**
Jansen et al, 2008 [59] (USA)	Cross-sectional n=224	75.4 ± 6.8 [65, 92] 62.5%	*Objective measures:* 1. Hand strength assessed by grip-force, tip pinch force, key pinch force and three jaw-chuck pinch force	1. Jamar dynamometer and B&L Engineering pinch gauges	ANOVA was used to analyze differences of grip and pinch force among five age groups (65–69 years, 70–74 years, 75–79 years, 80–84 years, and 85+ years).	Grip Force age group F=28.72, **p=0.01†** Key Pinch Force age group F=17.02, **p=0.01†** Three-Jaw-Chuck Pinch Force age group F=15.42, **p=0.01†** Tip Pinch age group F=6.55, **p=0.01†**

Prata & Scheicher, 2012 [70] (Brazil)	Cross-sectional n=70	70.5±5.0 81.4%	*Objective measures:* 1. Balance assessed by a scale 2. Cognitive impairment assessed by test *Self-reported measures:* 3. Functional independence in ADL evaluated by an index	1. Berg Balance Scale (BBS) 2. Mini-Mental State Examination (MMSE) 3. Barthel Index (BI)	The Spearman correlation coefficient was used to examine the relationship between the evaluation parameters.	Association between age and BBS r=-0.57, **p=0.0001†** Association between age and MMSE r=0.34, **p=0.0032†** Association between and BI r=-0.24, **p=0.04†**

Table 4: Characterization and summary of studies included in the review with classification of "Fair" in Downs and Black scale, listed by decreasing order of quality score (for those with same score alphabetic order was used). (Supplementary table S2)

Notes: AG – age group, ANOVA - Analysis of variance; M±SD – Mean plus Standard Deviation; NR – non reported; NS – non significant, * - study design non reported in the respective study, and thus classified by the reviewers; † - indicators with significative change or association with age.

ID	**Study Design** (Follow-up time) **Sample Size**	**Age** M±SD [range] % female	**Indicators** Objective & Self-reported	**Instrument**	**Main statistical strategy used to assess the influence of age**	**Significative change/ association with age**
Alcock et al., 2015 [34] (United Kingdom)	Cross-sectional n=39	71.5 ± 7.3 [60, 83] 100%	*Objective measures:* 1. Gait speed assessed by central part of 10 meter walk 2. Time to complete TUG 3. Time to compete one sit-to-stand cycle 4. Knee flexor and extensor concentric strength assessed by Hamstrings-to-Quadriceps ratio, Peak Knee Extensor and Flexor Moment (PKnee EM, PKnee FM) *Self-reported measures:* 5. Health and well-being status assessed by questionnaire	1. 10-meter walk 2. TUG test 3. Optoelectronic system 4. Dynamometer 5. Short Form Health Survey (SF-36)	Bivariate correlations (Pearson's r, R2 and significance level) expressed the strength of the relationship between each of the outcomes and age. Linear regression was computed for all outcomes using age as a single independent predictor (regression coefficient beta (β), significance level).	Gait speed (m/s) r=-0,57, R^2=32%, **p≤0.01†**; β=-0.017, **p≤0,001†** TUG time(s) r=0.53, R^2=28%, **p≤0.01†**; β=0.181, **p=0.001†** STS time (s) r =0,15, R^2=0%, p>0.05; β=-0.085, p=0.386 HQ ratio (%) r=-0.46, R^2=21%, **p≤0.01†**; β=-0.010, **p≤0,001†** PKnee EM(Nm/kg) r=-0.58, R^2=33%, **p≤0.01†**; β=-0.014, **p≤0.001†** PKnee FM(Nm/kg) r=-0.58, R^2=34%, **p≤0.01†**; β=-0.009, **p≤0.001†** SF-36: Physical Functioning r=-0.53, R^2=28%, **p≤0.01†**; β=-1.143, **p≤0.001†** Role-Physical r=-0.19, p=not computed due to ceiling effects Bodily Pain r=-0.30; R^2=9%, p>0.05; β=0.835, p=0.065 General Health r=-0.21; R^2=10%; p>0.05; β=-0.685, p=-0.059 Vitality r=-0.29; R^2=9%, p>0.05; β=-0.770, p=0,074 Social Functioning r=-0.03, p=not computed due to ceiling effects Role- Emotional r= -0,11, p= not computed due to ceiling effects Mental Health r=-0.06, R^2=0%, p>0.05; β=-0.105, p=-0.701 Mental Component r=0,01, R^2=0%, p>0.05; β=0.008, p=0.958 Physical Component r=-0,38, R^2=, **p≤0.01†**; β=-0.443, **p=0.022†**

Amarasena et al., 2018 [35] (Australia)	Cross-sectional n=354 AG (75-84) n=274 (≥85) n=80	NR 52%	*Self-reported measures:* 1. Self-rated oral health (SROH) assessed trough single question 2. Self-rated General health (SRGH) assessed trough single question	1. How would you rate the overall health of your teeth, dentures and gums? 2. 'In general, would you say your health is. . .?'.	SRGH and SROH responses dichotomized into categories 'poor/fair', 'good/very good/excellent' were cross-tabulated with age [AG 75–84, ≥85 years)] using chi-squared test. Adjusted analyses performed using log-binomial regression.	Good SROH (75–84) (37.3%), p≥0.05 (≥85) 29 (37.2%), p≥0.05 Good SRGH (75-84) n=153 (56.7%), p≥0.05 (≥85) n=50 (63.3%), p≥0.05 Good SROH: Prevalence ratio=0.90 (95% CI 0.64–1.27), p≥0.05 Good SRGH: Prevalence ratio=1.03 (95% CI 0.85–1.25), p≥0.05
Arroyo et al., 2007 [38] (Chile)	Cross-sectional n=377	Male 73,9 ± 6,1 [65, 91] Female 74,4 ± 6,6 [65, 95] 63,1%	*Self-reported measures:* 1. Functional ability assessed by questionnaire	1.1. ADL, IADL questionnaire (scale non-identified) 1.2. AADL (advanced activities of daily life) questionnaire including items of Rosow and Breslau and Index of basic physical activities – Nagi	Author defined the report of difficulties in at least 1 ADL or 1 AIVD or 2 AAVD to define the functional limitation. Multiple logistic regressions performed to study the association of functionality and mobility with age.	Multiple Logistic regression Male Age OR=1,04, IC 95%=0,975-1,117, p=0,122 Female Age OR=1,098, IC 95%=1.043-1.155, **p<0.001†**

Chang & Dong, 2014 [40] (USA)	Cross-sectional[*] n=3159	72.8 ± 8.3 [60, 105] 58.9%	*Objective measure:* 1. Cognitive function assessed by a battery of five cognitive function test	1.1. Global cognition: Chinese Mini-Mental State Exam (C-MMSE) 1.2. Episodic memory: summarized scores of immediate recall (East Boston Memory Test (EBMT) - Immediate Recall and delayed recall of brief stories in the EBMT (range 0–24) 1.3. Executive function: 11-item Symbol Digit Modalities Test (SDMT) 1.4. Working memory: Digit Backwards (DB) from Wechsler Memory Scale-Revised	A composite score (scale name+Z) for global cognitive function was calculated by transforming a participant's score on each cognitive test to a z score based on the M and SD of the distribution of the scores of all participants on that test, and then averaging z scores across tests. Spearman correlation coefficients were calculated to determine relationship between age and cognitive function. Based on the results of bivariate analysis, was performed multivariate analysis using linear regression models to report the effect of age and health-related variables on composite measure of function by cognitive domain.	Spearman Correlations Between Composite Scores of Cognitive Function Domains and Age GlobCog r=−0.33, **p<0.001†** C-MMSE Z r=−0.31, **p<0.001†** Episodic memory r=−0.28, **p<0.001†** SDMT Z r=−0.35, **p<0.001†** DB Z r=−0.22, **p<0.001†** Effect of age on composite measure of function by cognitive domain: Estimated Slope (SE) Global cognitive score −0.030 (0.002), **p<0.001†** SDMT Perceptual speed −0.034 (0.002), **p<0.001†** Episodic memory −0.031 (0.002), **p<0.001†** DB −0.020 (0.002), **p<0.001†** C-MMSE Z score −0.038 (0.002), **p<0.001†**

Chen et al., 2012 [42] (Taiwan)	Cross-sectional* n=384 Young-old (65-74) n=128 Middle-old (75-84) n=127 Old-old (≥85) n=129	79.2 ± 8.5 [65, 101] 49.0%	*Self-reported measures:* 1. ADL assessed by index and ability to complete 5 tasks independently 2. Physical Status assessed by report of chronic illness conditions *Objective measures:* 3. Physical Status assessed by cardiovascular-respiratory functions and body composition	1. Barthel index (BI) and Likert-type scale for the tasks: ability to walk outside, shop, take public transportation, do housework, ad manage money 2. Number of chronic diseases, frequency of doctor's visit, frequency of hospitalization 3. Respiration rate (times/min), Pulse rate (times/min), Breath-holding duration (s), Lung capacity (L) (TruZone Peak FlowMeter), Systolic and Diastolic blood pressure (mmHg) (sphygmomanometer (OMRON-HEM707), Body height (cm) and weight (kg), Body mass index, Body fat (%) (digital body fat scale TANITA-TBF521), Waist circumference (cm)	Analysis of variance and nonparametric Kruskal-Wallis analysis of variance were conducted to compare the three age groups. Post hoc Bonferroni and Mann-Whitney U tests were performed afterward on differences identified as significant.	Activities of daily living: BI F=4.2, **p=0.015†**, Y> O; Ability to walk outside X^2=50.0, **p<0.001†**, Y>O, M>O; Ability to shop X^2=65.4, **p<0.001†**, Y>M>O; Ability to take public transportation X^2=73.8, **p<0.001†**, Y>M>O; Ability to do housework X^2=37.6, **p<0.001†**, Y>M>O; Ability to manage money X^2=31.0, **p<0.001†**, Y>M>O Chronic illness conditions: Nº of chronic diseases F=0.2, p=0.787; Frequency of doctor's visit F=0.7, p=0.516; Frequency of hospitalization F=0.1, p=0.927 Cardiovascular-respiratory functions: Respiration rate F=4.3, **p=0.014†**, Y<O; Pulse rate F=0.9, p=0.393; Breath-holding duration F=11.1, **p<0.001†**, Y>M, Y>O; Lung capacity F = 29.4, **p<0.001†**, Y>M>O; Systolic blood pressure F = 1.9, p=0.146; Diastolic blood pressure F = 24.6, **p<0.001†**, Y>O, M>O Body composition: Body height F=3.4, **p=0.036†**, Y>O; Body weight F=19.7, **p<0.001†**, Y>O, M>O; Body mass index F=11.6, **p<0.001†**, Y>O, M>O; Body fat F = 10.0, **p<0.001†**, Y>O, M>O; Waist circumference F = 2.0, p=0.141

Ghinescu et al., 2014 [52] (Romania)	Cross-sectional n=547	71.64±5.33 58%	*Self-reported measures:* 1. ADL and IADL assessed by a scale 2. Self-rated health assessed by one question 3. Morbidity assessed by chronic conditions scale 4. Functioning assessed by questionnaire	1. Groningen Activity Restriction Scale 2. Respondents evaluated their health from poor, average, good, very good or excellent (1 to 5, respectively) 3. Report the number of chronic conditions in the past 12 months 4. Sort Form (SF)-20	Indicators relationship analyzed by factor analysis (principal component, varimax rotation). Factor scores per respondent on each component were calculated. Association of the socio-demographic data, psychological characteristics and social support with dimensions that resulted from factor analysis was analyzed using stepwise linear regression analysis.	By principal component analysis it was identified 3 factors: Factor 1 - denominated independent functioning; Factor 2 denominated suffering from chronic diseases; Factor 3 denominated psychological health Factor 1 Independent functioning: $\beta = -0.321$, **p<0.01†** Factor 2 Suffering from chronic diseases: $\beta = 0.101$, **p<0.05†** Factor 3 Psychological health: $\beta = -0.082$, **p<0.05†**
Hershman et al., 1995 [56] (USA)	Longitudinal Study (2 to 10 years) n=488	79.2 ± 3.1 [75, 85] 64.5%	*Objective and Self-reported measure:* 1. Prescription and nonprescription drug use queried during an interview with a nurse	1. Medication type and dose were ascertained by examination of prescription bottles and/or prior medical records.	Differences between means were analyzed using independent t tests. Differences between medication classes were analyzed using Chi square tests.	Medication Use as a Function of Age and Sex Male: Total use <80 vs >80, **p<0.05†**; Prescription use <80 vs >80, **p<0.05†**; Nonprescription use <80 vs >80, p≥0.05 Female: Total use <80 vs >80, p≥0.05; Prescription use <80 vs >80, p≥0.05; Nonprescription use <80 vs >80, p≥0.05 Frequency of Medication Use by Age ≤80 vs >80 Vitamins p=0.52; Diuretics p=0.60; NSAIDS p=0.96; GI p=0.20; Analgesics p=0.24; Sedatives p=0.08; Digoxin p=0.52; Nitrates p=0.27; Beta Blockers p=0.71; Antihistamines X2=10.5, **p=0.001†**; Eye p=0.49; Hypoglycemics p=0.14; Antiarrhythrnics p=0.98; Antidepressants X2 = 4.5, **p=0.03†**; Antibiotics p=0.38

Ignasiak et al., 2020 [57] (Poland)	Cross-sectional n=5367	69,63±7,06 [60, 93] Male 69,91±6,86 Female 69,55±7,11 77.6%	*Objective measure:* 1. Functional fitness assessed by six tests 2. Body composition assessed by Body mass index	1. Senior Fitness Test including 30-Second Chair Stand Test (STS) (perform as many correct lifts from the chair as possible within 30s); Arm curl test (AC) (perform as many correct forearm bends as possible within 30s); Chair Sit and Reach test (CSR) (distance from the middle finger to the toes is measured); Back Scratch test (BS) (distance between the middle fingers of both hands is measured); 8-Foot Up-and-Go Test (8UG) (time needed to complete the task) and 6-Minute Walk Test (6MWT) (distance covered by the examined person in the given time) 2. Height and weight assessed by SECA measuring device	Differences between means in the groups were analyzed using two-factor analysis of variance ANOVA with NIR post hoc test. The F statistic was counted for main effects, and the significance of inter-group differences was assessed.	ANOVA: BMI F=2.22, **p=0.0499†**; STS F=34.44; AC F=75.41; CSR F=13.58; BS F=33.39; 8UG F=69.32; 6MWT F=85.73, all **p=0.0000†** NIR post hoc test for comparisons of male and female age groups Male: STS (60–64)vs(70–74) p=0.9263; (65–69)vs(75–79) **p=0.0020†**; (70–74)vs(80–84) **p=0.0003†**; (75–79)vs(85+) **p=0.0000†**; AC (60–64)vs(70–74); (65–69)vs(75–79); (70–74)vs(80–84) **p=0.0000†**; (75–79)vs(85+) **p=0.0001†**; CSR (60–64)vs(70–74) **p=0.0020†**; (65–69)vs(75–79) p=0.9380; (70–74)vs(80–84) p=0.6136; (75–79)vs(85+) **p=0.0094†**; BS (60–64)vs(70–74) **p=0.0177†**; (65–69)vs(75–79) **p=0.0020†**; (70–74)vs(80–84) **p=0.0101†**; (75–79)vs(85+) **p=0.0000†**; 8UG (60–64)vs(70–74) p=0.0719; (65–69)vs(75–79); (70-74)vs(80–84) **p=0.0000†**; (75–79)vs(85+) **p=0.0077†**; 6MWT (60–64)vs(70–74) **p=0.0003†**; (65–69)vs(75–79); (70–74) vs(80–84); (75–79)vs(85+) **p=0.0000†** Female: STS (60–64)vs(70–74); (65–69)vs(75–79); (70–74)vs(80–84); (75–79)vs(85+) **p=0.0000†**; AC (60–64)vs(70–74); (65–69) vs(75–79); (70–74)vs(80–84); (75–79)vs(85+) **p=0.0000†**; CSR (60–64) vs(70–74), (75–79) vs (85+) **p=0.0000†**; (65–69)vs(75–79) **p=0.0003†**; (70–74) vs (80–84) p=0.1917;; BS (60–64) vs (70–74) **p=0.0009†**; (70–74) vs (80–84) **p=0.0005†**; (65–69) vs (75–79, (75–79) vs (85+) **p=0.0000†**; 8UG (60–64) vs (70–74); (65–69) vs (75–79); (70–74)vs(80–84); (75–79)vs(85+) **p=0.0000†**; 6MWT (60–64) vs (70–74); (65–69) vs (75–79); (70–74) vs (80–84); (75–79) vs (85+) p=**0.0000†**

Marques et al., 2014 [61] (Portugal)	Cross-sectional n=4712	75.0 ± 7.2 [65, 103] 66.2%	*Objective measures:* 1. Functional fitness assessed by six tests 2. Anthropometric Measures assessed by BMI level (kg/m^2) and size of waist circumference (cm)	1. Senior Fitness Test which includes 30-Second Chair Stand Test (STS) (perform as many correct lifts from the chair as possible within 30s); Arm curl test (AC) (perform as many correct forearm bends as possible within 30s); Chair Sit and Reach test (CSR) (distance from the middle finger to the toes is measured in cm); Back Scratch test (BS) (distance between the middle fingers of both hands is measured in cm); 8-Foot Up-and-Go Test (time needed to complete the task in seconds) and 6 –Minute Walk Test (6MWT) (distance in meters covered by the examined person in the given time) 2. Portable stadiometer and balance weighing scales for BMI and heavy-duty inelastic tape for waist circumference	A two-way ANOVA was used to test for main effects and interaction effects across gender and age groups (65–69, 70–74, 75–79, 80–84, and ≥85 years). Bonferroni post hoc tests were then used when warranted (p<0.05).	STS: Male **p<0.001†**: (70-74)vs(65–69), (75-79)vs(65–69) and (70–74), (80-84)vs(65–69), (70–74) and (75-79), (≥85)vs(65–69), (70–74) and (75-79); Female **p<0.001†**: (75-79) vs (65–69) and (70–74), (80–84) vs (65–69), (70-74) and (75–79), (≥85) vs all AG AC: Male **p<0.001†**, (75-79) vs (65–69) and (70–74), (80-84)vs (65–69), (70–74) and (75-79), (≥85)vs(65–69), (70–74) and (75-79) Female **p<0.001†**, (75-79)vs(65–69) and (70–74), (80-84)vs(65–69), (70–74) and (75-79), (≥85) vs (65–69), (70–74) and (75-79) 6MWT: Male **p<0.001†**, (70-74)vs(65–69), (75-79)vs(65–69) and (70–74), (80-84)vs(65–69), (70–74) and (75-79), (≥85) vs all AG; Female **p<0.001†**, (70-74)vs(65–69), (75-79)vs(65–69) and (70–74), (80-84)vs(65–69), (70–74) and (75-79), (≥85) vs all AG CSR: Male **p<0.001†**, (75-79)vs(65-69), (80-84)vs(65–69), (70–74) and (75-79), (≥85) vs (65–69), (70–74) and (75-79); Female **p<0.001†**, (75-79) vs (65–69) and (70–74), (80-84) vs (65–69), (70–74) and (75-79), (≥85)vs(65–69), (70–74) and (75-79) BS: Male **p<0.001†**, (70-74) vs (65-69), (75-79)vs(65–69) and (70–74), (80-84)vs(65–69) and (70–74), (≥85)vs(65–69), (70–74) and (75-79); Female **p<0.001†**, (70-74)vs(65-69), (75-79) vs (65–69) and (70–74), (80-84)vs(65–69), (70–74) and (75-79), (≥85)vs(65–69), (70–74) and (75-79) 8UG: Male **p<0.001†**, (70-74)vs(65-69), (75-79)vs(65–69) and (70–74), (80-84)vs(65–69) and (70–74), (≥85)vs all AG; Female **p<0.001†**, (70-74)vs(65-69), (75-79)vs(65–69) and (70–74), (80-84) vs(65–69), (70–74) and (75-79), (≥85)vs AG Body-mass index: Male p=0.123; Female **p<0.001†**, (≥85)vs (65–69) and (70–74) Waist circumference: Male p=0.597; Female **p=0.001†** (80-84)vs (65–69) and (70–74)

Nakamura et al., 2017 [64] (Japan)	Cross-sectional n=142	74.26±5.86 [60, 90] 100%	*Objective measures:* 1. Cognitive function 2. Locomotive syndrome	1. Mini-Mental State Examination (MMSE) 2. 25-question Geriatric Locomotive Function Scale (GLFS-25).	Participants categorized into MMSE score ≤26 group and MMSE score >26 group, and into an GLFS-25 score ≤16 and GLFS-25 score >16. Age was compared between the cognitive MMSE ≤26 and MMSE>26 groups and between the LS and non-LS groups by Student t-test. The odds ratios (ORs) of measurements or LS status for an MMSE score ≤26 were calculated using univariate and multiple logistic regression analysis. Age, percent body fat, GLFS score, and LS were used as independent variables, and MMSE ≤26 as a dependent variable.	Student’s t-test MMSE >26 vs ≤26 groups **p=0.014†** GLFS-25 >16 vs ≤16 groups **p<0.001†** Univariate logistic regression analysis Age OR=1.10, CI (1.02–1.20), **p=0.015†**

Pisciottano et al., 2014 [68] (Brazil)	Cross-sectional n=100	70.76±4.92 [65, 85] 100%	*Objective measures:* 1. Physical ability assessed by three performance tests 2. Appendicular lean mass (ALM) obtained by the sum of lean mass of arms and legs, total body fat (kg/ %) 3. Lower limbs strength assessed by peak torque for knee extension (KES) and flexion (KFS) at 60 ° per second	1a. Dynamic gait index (DGI) 1b. Timed Up and Go test (TUG) 1c. Berg Balance test (BBT) 2. Dual-emission Xray densitometer (DPX Md +, GE - Lunar Radiation Corporation, Madison, WI, Usa). 3. Isokinetic dynamometer (Cybex 125 dynamometer AP, Chattanooga, TN)	Correlations between age, anthropometric parameters, BMD, lean mass, fat mass, physical tests and strength were investigated by spearman and Pearson's correlation tests. Variables with significant correlation were used for multiple linear regression models to identify the main outcomes in the study: ALM, KES, KFS and the physical tests (DGI, TUG and BBT)	Age correlations reported: TUG, BBT and DGI r=0.28-0.14, **p<0.001†**; TUG r=0.28, **p<0.001†**; BTT, identified as significantly correlated but p-value non reported; KES r=-0.27, **p<0.001†**; KFS r=-0.22**, p<0.05†** Multiple linear regression (Adjusted $R^2 – R^2$) ALM-12.28+0.03xage+0.09xweight+11.38xheight+0.02xKES,R^2=0.72 KES 32.06-1.15xage+0.02xweight+52.17xheight+3.67xALM, R^2=0.35 KFS 21.85-0.78xage-0.05xweight+28.06xheight+2.65xALM, R^2=0.28 TUG 9.50+0.08xage+0.02xweight-4.08xheight-0.01xKES, R^2=0.18 BBT 59.13-0.11xage-0.03xweight+2.56xheight+0.01xKES, R^2=0.13 DGI 20.31-0.03xage-0.02xweight+2.38xheight+0.02xKES, R^2=0.10
Chao et al., 2013 [41] (China)	Cross-sectional n=849 AG (60-64) n=581 (65-79) n=226 (80+) n=38	67.4 ± 7.7 52.7%	*Self-reported measures:* 1. Body function, Self-care ability function, Emotional personality, Memory function and Social adaptability assessed by questionnaire	1. Elderly Health Assessment Scale	ANOVA was used to compare the Elderly Health Assessment subscales between different groups according to demographic classification [(60-64),(65-69),(70-74),(75-79), (80+)]. Ordinal logistic regression, was used to analyze the main factors affecting the Elderly Health Assessment Scale	ANOVA Body Function F= 2.50, **p=0.04†**; Self-care ability F=6.49, **p<0.01†** Physical health F=4.83, **p=0.01†**;Emotional personality F=1.03, p=0,41 Memory function F=7.65, **p<0.01†**; Mental health F=5.27, **p<0.01†** Social adaptability F=2.36, p=0.05 Ordinal logistic regression AG (60-80+) OR (95%CI)=2.01 (1.01-4.03), p=0,05 AG (70-80+) years OR (95%CI)=1.43 (0.84-1.84), p=0.30

Ekström et al., 2016 [49] (Sweden)	Cross-sectional n=768 AG (67–70) n = 371 (79–89) n = 397	AG md (q1-q3) (67-70) 68 (67–69) (79-89) 84 (81–87) AG (67-70) 57.1% (79-89) 74.6%	*Self-reported measures:* 1. Environmental barriers and accessibility assessed by questionnaire 2. Perception physical environment support performance daily activities in the home assessed by questionnaire 3. Home tie assessed by questionnaire 4. External control beliefs in relation to home assessed by questionnaire 5. Housing satisfaction assessed with the single question 6. Psychological functio assessed by questionnaire 7. Symptoms assessed by checklist 8. Perceived functional independence (PFI) addressed by a single question 9. Total number of functional limitations calculated by the HE 10. ADL assessed by scale	1. Housing Enabler (HE) instrument 2. Usability in My Home questionnaire (UIMH) 3. 28-item Meaning of home questionnaire 4. Housing-related Control Beliefs Questionnaire (HCQ) 5. “Are you happy with the conditions of your home?” adapted from “Housing Options for Older People” Questionnaire 6. Ryff scales of Psychological Wellbeing 7. Presence of symptoms 8. “All in all, how would you evaluate your own independence, i.e. in performing activities of daily living?” 9. Presence of limitations scored between 0 to 12. Use of mobility devices 10. ADL Staircase	Differences between age cohorts were tested non-parametrically using the Mann–Whitney U test. P-values were corrected according to Bonferroni’s method.	No. of environmental barriers (HE): Outdoors **p=0.004†**, Entrances **p=0.019†**, Indoors **p<0.001†**, Total **p<0.001†** Accessibility score (HE): Outdoors **p<0.001†**, Entrances **p<0.001†**, Indoors **p<0.001†**, Total **p<0.001†** UIMH: Activity p=0.289, Environmental p=0.777 Meaning of home: Physical p<0.001†, Behavioral p=1.0, Cognitive-emotional p=1.0, Social **p=0.027†** Housing related control beliefs (HCQ) External control **p<0.001†** Housing satisfaction p=1.0 Psychological well-being: Autonomy p=1.0, Purpose in life **p<0.001†** Symptoms: Total p=0.126, Tension p=1.0, Gastro-urinary p=0.252, Musculoskeletal p=0.669, Metabolism p=0.201, Heart-lung p=1.0, Head **p<0.001†** PFI **p<0.001†** Functional limitations (HE) **p<0.001†** Mobility device use Indoors: Cane/crutch; Walking frame **p<0.001†**, Wheelchair p=1.0 Outdoors: Cane/crutch; Walking frame **p<0.001†**, Wheelchair p=0.028 Activities of daily living Independent without difficulty **p<0.001†**; Independent with difficulty **p=0.036†**; Dependent IADL **p<0.001†**; Dependent IADL and PADL **p<0.001†**; Dependent IADL and PADL **p<0.001†**

Fastame et al., 2020 [50] (Italy)	Cross-sectional*	n=53 AG (80–85) n=20 (90–95) n=17 (99–105) n=16	[80, 105] AG (80–85) 82.6±1.9 (90–95) 91.3±1.2 (99–105) 101.1±1.8 49,1%	*Self-reported measures:* 1. Perceived psychological well-being assessed by questionnaire 2. Socially desirable response assessed by inventory	1. Psychological Well-Being and Aging Questionnaire (PWAQ) [total score (PWAQ-tot), individual's coping strategies (PWAQ-COP), emotional competency (PWAQ-EC); personal satisfaction (PWAQ-PS)] 2. Marlowe and Crown Social Desirability Scale (MCSDS)	The effect of age group on total and subscales of psychological well-being scores was determined using Multivariate Analysis of Covariance (MANCOVA). Social desirability was included as a covariate. ANOVA was conducted to explore the impact of age group on the self-reported social desirability dimension.	Psychological well-being Wilks' Lambda=0.62, df=8;92, **p=0.004†** Social desirability Wilks' Lambda=0.83, df=4;46, p=0.07 PWAQ-COP dimension F(2,49)=6.72, **p=0.003†**; PWAQ-tot F(2,49)=0.97, p=0.39; PWAQ-EC F(2,49)=0.50, p=0.61; PWAQ-PS F(2,49)=1.06, p=0.35 Bonferroni post-hoc comparisons: PWAQ-COP (99–105) vs (80–85) **p=0.002†**; (99–105) vs (90–95) p=0.14 ; (80–85) vs (90–95) NR ANOVA: Social desirability F(2,50) = 2.43, p=0.10

Hara et al., 2020 [54] (Japan)	Cross-sectional*	n=74	76.8 ± 9.0 Male md (IR) 77 (71.5-82.5) Female 77 (74-82) 68.9%	*Objective measures:* 1. Number of teeth assessed by dentist 2. Masticatory function assessed by maximum bite force (MBF) 3. Muscle quantity assesssed by masseter muscle thickness (MMT) 4. Muscle quality assessed by masseter muscle echo intensity (MMEI) 5. Movement during contraction assessed by the displacement of the masseter muscle during forceful biting (MMD) and time of force production (TFP)	1. NA 2 .Pressure-sensitive film (Dental prescale 50 HR Type R; Fujifilm) and OCCLUZER device (FPD-707; Fujifilm). 3. 4. Ultrasonic diagnostic apparatus (MySono U6; Samsung Medison, Inc, Seoul, Korea) with a linear probe (broadband frequency, 5-12 Hz; gain, 45 dB; depth, 2.7 cm) 5. M-mode ultrasonography with a linear probe	Correlations objective measures, and age were assessed using bivariate correlation analysis, using Pearson's correlation analysis for parametric data and Spearman's rank test for non-parametric data. Correlations among MBF, MMEI and MMT, was tested by multivariate linear regression analysis for MBF, with MMT and MMEI (model 1); thereafter, MMD and TFP were added (model 2). To study the relationship among MMD, MMT and MMEI, multivariate linear regression analysis for MMD was performed, with adjustment for number of teeth, age and sex.	Correlations Number of teeth r=-0.505, **p<0.05†**; MBF r=-0.228, **p=0.049†** MMT r=-0.273, **p<0.05†**; MMEI r=0.112, p>0.05; MMD r=0.153, p>0.05; Time of force production r=0.023, p>0.05 Multivariate linear regression analysis for MBF Model 1 (Age, Sex, Number of teeth, MMT, MMEI) R^2=0.386 Age B=11.192, 95% CI (-5.707, 28.090), β=0.157, p=0.191, Variance Inflation Factor VIF=1.591 Model 2 (Age, Sex, Number of teeth, MMT, MMEI, MMD, TFP) R^2=0.440 Age B=6.532, 95% CI (-10.373, 23.437), β=0.092, p=0.443, VIF=1.666 Multivariate linear regression analysis for MMD R^2=0.417 Age B=0.034, 95% CI(-0.005, 0.074), β=0.204, p=0.088, VIF=1.594

Hayashi et al., 2002 [55] (Japan)	Cross-sectional n=151	70 ± 5 [60, 80] 100%	*Objective measures:* 1. Physical strength assessed by grip strength, vertical jump height, jumping reaction time, time required to get up from a recumbent position to sitting down on a chair, sit and reach distance, time of balancing on one leg with eyes closed and tapping score for 30 seconds 2. Cerebral functions measuring occupational aptitude by questionnaire *Self-reported measures:* 3. Mental health status assessed by screening questionnaire	1. Digital grip dynamometer (Takei Kiki Co., Tokyo, Japan), Jump-meter (VINE Co., Tokyo, Japan), tapping counter (Takei Kiki Co., Tokyo, Japan) 2. General Aptitude Test Battery (GATB) 3. General Health Questionnaire (GHQ)	Bivariate correlation coefficients (Spearman's rank correlation coefficients) between age and physical strength, cerebral functions, and GHQ scores	Physical strengths Grip strength (kg) r=-0.240, **p<0.01**†; Vertical jump height (cm) r=-0.301, **p<0.001**†; Jumping reaction time (sec) r=0.216, **p<0.01**†; Time to stand up and sit down (sec) r=0.204, **p<0.05**†; Sit and reach distance (cm) r=-0.197, **p<0.05**†; Time of balancing on one leg with eyes closed r=-0.343, **p<0.001†;** Tapping score (beat/sec) r=-0.251, **p<0.01**† General Aptitude Test Battery sub-tests Motor coordination r=-0.411, **p<0.001**†; Form perception r=-0.190, **p<0.05**†; Verbal aptitude r=-0.213, **p<0.01**†; Spatial perception r=-0.147, p>0.05; Manual dexterity r=-0.369, **p<0.001**†; Finger dexterity r=-0.425, **p<0.001**† GHQ sub-scales Somatic symptoms r=-0.021, p>0.05; Anxiety/insomnia r=-0.051, p>0.05; Social dysfunction r=0.162, **p<0.05**†; Severe depression r=0.224, **p<0.01**†

Neri et al., 2012 [65] (Brazil)	Cross-sectional* n=900	72.78±5.82 [65-97] Performed MMSE sentence 72.24±5.74 Not performed MMSE sentence 73.74±5.85 69.3%	*Objective measures:* 1. Cognitive status 2. Language performance	1. MMSE 2. MMSE sentence (Verbal fluency - number of words produced; Grammatical complexity - number of phrases or interrelated ideas)	Chi-square test used to evaluate the performance in the MMSE sentence, stratified by age (65–69; 70–74; 75–79; ≥80) Participants who responded to the MMSE sentence was compared to those who did not answer as to age (65–69; 70–74; 75–79; ≥80) by Mann–Whitney U test. Comparison of cognitive and textual performance according to age Kruskal–Wallis test and Dunn post hoc	Performance in the MMSE sentence by age group $\chi2$ =24.18, df=9, **p=0.004†** Age comparison of elderly adults whose answers to the MMSE sentence were included versus excluded **p<0.001†** Comparison of cognitive and textual performance according to age MMSE Total Score **p<0.001†**, (≥80) vs (65-69) Number of Words p=0.101 Number of ideas p=0.681
Salvà et al., 2005 [72] (Spain)	Cross-sectional n=443	74,6 ± 6.9 59,1%	*Objective measure:* 1. Gait and Balance assessed by test	1. Performance Oriented Mobility Assessment (POMA)	Comparison of POMA impairments between age groups (< 71, 71-75, 76-80, 81-85, > 85) by Kruskal-Wallis test and Mann-Whitney test to compare impairments between two groups	Kruskal-Wallis test 3 or more impairments in POMA **p<0.001†** Mann-Whitney test < 71, 71-75 vs >85, **p<0.001†**
Choudhary, 2020 [43] (India)	Cross-sectional* n=60 AG (60-69) n=20 (70-79) n=20 (80-89) n=20	(60-69) 63.95±2.50 (70-79) 73.35±2.36 (80-89) 83.35±2.25 50%	*Objective measures:* 1. Functional performance assessed by number of step performed in 6 minutes 2. Balance assessed by the time to complete sequence of directions change	1. 6 minute step test (6MST) 2. Four Square Step	ANOVA was used to study the difference among scores of Six Minute Step Test and Four Square Step test for subjects in all the 3 age groups.	Six Minute Step Test Significant difference between (60-69) vs(70-79); (70-79) vs (80-89); (80-89) vs (60-69) F-value=21.96, **p=0.000†** Four Square Step Test Significant difference between (60-69) vs (70-79); (70-79) vs (80-89); (60-69) vs (80-89) F- value=8.97, **p=0.000†**

Confortin & Barbosa, 2015 [45] (Brazil)	Cross-sectional n=270	73.2 ± 8.8 [60, 100] 100%	*Objective measures:* 1. Lower limb muscle strength/resistance (LLMS) assessed by time to stand up and sit down 5 times 2. Handgrip strength (HGS) assessed by the maximum of two grip pressure trials	1. "Chair stand" test 2. Mechanical dynamometer (Takei Kiki Kogyio TK 1201, Japan)	Poisson regression (crude and adjusted; 95%CI) to verify association between HGS, LLMS and age. The variables that presented statistical significance of at least 20% (p≤0.20) in the crude analyses were included in the adjusted analyses, according to the hierarchical model. At each level of the adjusted analyses, the backward selection technique was used. Level 1, 2 and 3 variables were adjusted among themselves, and those that obtained p≤0.20 were kept in models for adjustment in the following levels.	LLMS Crude Analysis (Test of Wald for linear trend) PR (95% CI) 1.04 (1.03-1.06), **p≤0.001†** Adjusted Analysis (Test of Wald for linear trend) 1.03 (1.02-1.05), **p≤ 0.001†** HGS Crude Analysis (Test of Wald for linear trend) PR prevalence ratio (95% CI) 1.03 (1.01-1.05), **p=0.006†** Adjusted Analysis (Test of Wald for linear trend) 1.03 (1.01-1.05), **p=0.02†**
Incel et al., 2009 [58] (Turkey)	Cross-sectional n=24 AG Younger elderly (65–70) n=13 Older elderly (70–79) n=11	69.16±3.73 [65, 79] AG (65–70) 66.46±1.45 (70-79) 72.18±2.81 62.5%	*Objective measures:* 1. Handgrip strength assessed by dinamometry 2. Tip pinch strength assessed by finger prehension force *Self-reported measures:* 3. Self-estimated hand function (SEHF) assessed by scale 4. Disability assessed by a scale 5. IADL assessed by a scale 6. General health assessed by scale	1. Jamar dynamometer (JA Preston Corp., Ontario, Canada) 2. Manual pinchmeter that measures finger prehension force 3. Visual analog scale for the perception of the use the hand to perform activities 4. Duruo¨ z hand index (Cochin scale) 5. IADL scale (Lawton and Brody, 1969) 6. Short form 36	Comparisons between older adults subgroups (according to sex and age) were tested using t-tests and Mann–Whitney U test.	Handgrip strength p>0.05 Tip pinch strength p>0.05 SEHF p>0.05 Dreiser hand function index p>0.05 IADL p>0.05 SF-36 p>0.05

Sauvel et al., 1994 [74] (France)	Longitudinal Study* (1 year) n=1850	NR NR	*Self-reported measures:* 1. ADL dependence assessed by index 2. IADL dependence assessed by questionnaire 3. Mobility assessed by scale	1. Katz Index of ADL 2. Instrumental activities of daily living by Lawton & Brody, 1969 3. Confinement scale	Age differences between individuals that developed dependence after one year and individuals who maintained independence in ADL, IADL and Mobility assessed by Chi-squared test. Independent effect of age in becoming dependent assessed by logistic regression for ADL, IADL and Mobility	Chi-squared test ADL **p<0.001†** IADL **p<0.001†** Mobility **p<0.001†** Logistic regression ADL OR=1.07, CI 95%=1.04-1.11 IADL OR=1.11, CI95%=1.07-1.14 Mobility OR=1.09, CI95%=1.05-1.14
Sherman & Reuben, 1998 [75] (USA)	Cross-sectional n=363	75.9 ± 5.9 NR	*Objective measures:* 1. Lower and upper extremity function 2. Lower extremity function, balance gait, strength and endurance assessed by test	1. Physical Performance Test 2. National Institute on Aging Battery	Comparison of the age between the group below the median and above the median of Physical Performance Test and National Institute on Aging Battery (test non reported)	Physical Performance Test Age **p<0.0001†** National Institute on Aging Battery Age **p<0.0001†**
Smee et al., 2012 [76] (Australia)	Cross-sectional* n=32 AG 65–74 n = 10 75–84 n = 16 >85 n = 6	77.9 ± 7.7 [65-92] AG 65-74 68.8 ± 2.7 75-84 79.6 ± 3.26 (>85) 88.8 ± 7.70 47%	*Subjective measures:* 1. General health assessed by scale *Objective measures:* 2. Physical functionality assessed tests	1. 12-Item Short-Form Health Survey (SF-12) with the physical (physSF-12) and mental (mentSF-12) subscales identified 2. Continuous-Scale Physical Functional Performance (CS-PFP 10) (total score and five physical domains—upper body strength, lower body strength, upper body flexibility, balance, and endurance)	Test comparing General health and Physical functionality between age groups are non-reported. Pearson product-moment correlation coefficients were used to examine bivariate relationships between all variables and age	CS-PFP10 total score (65-74) vs (>85), **p<0.01†** Upper body strength (65-74) vs (>85), **p<0.01†** Lower Body strength (65-74) vs (>85), **p<0.01†** Upper body flexibility NS Balance (65-74) vs (>85), **p<0.01†** Endurance (65-74) vs (>85), **p<0.01†** SF12: physSF12 NS; mentSF12 NS Pearson Correlation: CS-PFP10 total score r=−0.61, **p<0.01†** Upper body strength r=−0.45, **p<0.01†** Lower Body strength r=−0.52, **p<0.01†** Upper body flexibility r=−0.44, **p<0.05†** Balance r=−0.63, **p<0.01†** Endurance r=−0.62, **p<0.01†** SF12phys r=−0.28, p>0.05; SF12men r=−0.04, p>0.05

Table 5: Characterization and summary of studies included in the review with classification of "Poor" in Downs and Black scale, listed by decreasing order of quality score (for those with same score alphabetic order was used). (Supplementary table S3)

Notes: AG – age group, ANOVA - Analysis of variance; M±SD – Mean plus Standard Deviation; NR – non reported; NS – non significant, * - study design non reported in the respective study, and thus classified by the reviewers; † - indicators with significative change or association with age.

ID	**Study Design** (Follow-up time) **Sample Size**	**Age** M±SD [range] % female	**Indicators** Objective & Self-reported	**Instrument**	**Main statistical strategy used to assess the influence of age**	**Significative change/ association with age**
Andrade et al., 2018 [36] (Brazil)	Cross-sectional* n=81 AG (60-69) n=30 (70-79) n=40 (≥80) n=11	NR 58%	*Objective measures:* 1. Lower extremities strength/endurance assessed by time to perform 5 stand-to-sit 2. Postural control parameters assessed by the recording of co-ordinates of the body's CoP during 30 seconds	1. Chair stand test 2. Piezoelectric force platform (Footwork Pro AM CUBE, France)	Kurskall-Wallis test was used to compare lower limb strength and stabilometric variables among the studied age groups and a Mann-Whitney test with Bonferroni correction for multiple comparisons was used as a post-hoc test	Chair stand test (≥80) - (60-69), **p<0.05†** Co-ordinates of the body's CoP Normalized AnteroPosterior displacement (≥80) - (60-69) **p<0.05†** (≥80) - (70-79) **p<0.05†** Normalized MedioLateral displacement (70-79) - (60-69) **p<0.05†** (≥80) - (60-69) **p<0.05†**
Poon et al., 1992 [69] (USA)	Cross-sectional* n=165	≥60 NR	*Objective measures:* 1. Fluid and crystallized intelligence estimated by subtests of vocabulary, arithmetic, picture arrangement and block design 2. Acquisition (primary memory) and retrieval (secondary memory) of information evaluated by a task 3. Tertiary memory measured by a test 4. Problem-solving ability evaluated by problem resolution	1. Wechsler Adult Intelligence Test 2. Learning task in which pairs of high and low frequency words were employed 3. Test of the names and faces of six immediate past presidents of the United States 4. Everyday problems encountered by most people living at home	Influences of Age Group on Cognitive Performances by ANOVA (age group 60s, 80s, ≥100)	Influences of Age Group on Cognitive Performances Fluid intelligence F=33.85 (2,137), **p=0.0001†** Crystallized intelligence F=25.72 (2,149), **p=0.0001†** Primary memory F=41.73 (2,149), **p=0.0001†** Secondary memory F=33.79 (2,146), **p=0.0001†** Tertiary memory F=48.39 (2,160), **p=0.0001†** Problem solving F=2.22 (2,161) p=0.1123

Araújo & Ribeiro., 2011 [37] (Portugal)	Cross-sectional[*] n=991 AG (65-69) n=290 (70-79) n=494 (≥80) n=207	74,1 ± 6.5 [65, 101] 70,4%	*Self-reported measures:* 1. Subjective Health assessed trough 3 questions 2. Objective Heath assessed trough 3 questions 3. Function assessed by questionnaire	1. General health self-assessment -"In general, do you think your health is…?"; Self-assessment of health compared to the past (question NR); Self-assessment of health compared to others "Comparing with those close to you, do you think your health is…?" 2.1 Medical diagnoses (presence of diseases for which participants took medication) 2.2 Vision ability 2.3 Audition ability 3. Scale of ADL	Descriptive analysis of selected variables, controlling for different sociodemographic variables, in three age groups: (65-69), (70-79) and (≥80). Statistical tests non reported.	Subjective Health General health self-assessment p= 0.269 Self-assessment of health compared to the past p=0.052 Self-assessment of health compared to others **p<0,05†** Objective Heath Medical diagnoses p=0,08 Vision ability **p< 0,05†** Audition ability **p< 0,05†** Function ADL **p<0,05†** IADL **p<0,05†**

Appendix XIII - Supplementary Materials of Study II

Database search - Scopus

Search history — Combine queries... e.g. #1 AND NOT #3

18	((TITLE-ABS-KEY ("aged" OR "elder*" OR "older adult*" OR "aged, 80 and over" OR "older person*" OR "centenarian" OR "sexagenarian*" OR "septuagenarian*" OR "octogenarian*" OR "nonagenarian*")) AND (TITLE-ABS-KEY ("Movement" OR "Musculoskeletal Physiological Phenomena" OR "Biomechanical Phenomena" "biomechanics" OR "movement evaluation" OR "Task Performance and Analysis" OR "task" OR "gait" OR "sit-to-stand" OR "Stair Climbing" OR "Walking" OR "kinetic*" OR "Exercise Test")) AND (TITLE-ABS-KEY··· View More	311 document results
17	((TITLE-ABS-KEY ("aged" OR "elder*" OR "older adult*" OR "aged, 80 and over" OR "older person*" OR "centenarian" OR "sexagenarian*" OR "septuagenarian*" OR "octogenarian*" OR "nonagenarian*")) AND (TITLE-ABS-KEY ("Movement" OR "Musculoskeletal Physiological Phenomena" OR "Biomechanical Phenomena" "biomechanics" OR "movement evaluation" OR "Task Performance and Analysis" OR "task" OR "gait" OR "sit-to-stand" OR "Stair Climbing" OR "Walking" OR "kinetic*" OR "Exercise Test")) AND (TITLE-ABS-KEY··· View More	322 document results
16	(TITLE-ABS-KEY ("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis"))	2,398,186 document results
15	(TITLE-ABS-KEY ("aged" OR "elder*" OR "older adult*" OR "aged, 80 and over" OR "older person*" OR "centenarian" OR "sexagenarian*" OR "septuagenarian*" OR "octogenarian*" OR "nonagenarian*")) AND (TITLE-ABS-KEY ("Movement" OR "Musculoskeletal Physiological Phenomena" OR "Biomechanical Phenomena" "biomechanics" OR "movement evaluation" OR "Task Performance and Analysis" OR "task" OR "gait" OR "sit-to-stand" OR "Stair Climbing" OR "Walking" OR "kinetic*" OR "Exercise Test")) AND (TITLE-ABS-KEY··· View More	359 document results
14	TITLE-ABS-KEY ("Principal Component Analysis" OR "PCA")	255,172 document results
13	TITLE-ABS-KEY ("Movement" OR "Musculoskeletal Physiological Phenomena" OR "Biomechanical Phenomena" "biomechanics" OR "movement evaluation" OR "Task Performance and Analysis" OR "task" OR "gait" OR "sit-to-stand" OR "Stair Climbing" OR "Walking" OR "kinetic*" OR "Exercise Test")	206,049 document results
12	TITLE-ABS-KEY ("aged" OR "elder*" OR "older adult*" OR "aged, 80 and over" OR "older person*" OR "centenarian" OR "sexagenarian*" OR "septuagenarian*" OR "octogenarian*" OR "nonagenarian*")	6,010,627 document results

Showing all recent searches | View 5 most recent only

Top of page

Database search - Web of Science

7	**#4 NOT #5** and **2022** or **2021** or **2020** or **2019** or **2018** or **2017** or **2016** or **2015** or **2014** or **2013** or **2012** or **2011** or **2010** or **2009** or **2008** or **2007** or **2006** or **2005** or **2004** or **2003** or **2002** (Publication Years)	228	Add to query
6	**#4 NOT #5**	245	Add to query
5	**TS=(("randomized controlled trial" OR "controlled clinical trial" OR "clinical trial" OR "systematic review" OR "meta-analysis"))**	758,491	Add to query
4	**#1 AND #2 AND #3**	254	Add to query
3	**TS=((“Principal Component Analysis" OR "PCA”))**	166,672	Add to query
2	**TS=((“Movement" OR “Musculoskeletal Physiological Phenomena” OR “Biomechanical Phenomena” "biomechanics” OR “movement evaluation” OR “Task Performance and Analysis” OR “task” OR “gait” OR ”sit-to-stand” OR “Stair Climbing” OR “Walking” OR “kinetic*” OR “Exercise Test”))**	2,725,781	Add to query
1	**TS=((“aged" OR "elder*” OR “older adult” OR “older person*” OR “aged, 80 and over” OR “centenarian*” OR “sexagenarian*” OR “septuagenarian*” OR “octogenarian*” OR “nonagenarian*”).)**	1,007,230	Add to query

Appendix XIV – Supplementary material of Study III

Supplementary Information

Methodological considerations for older adult's kinematic analysis: a scoping review

Search strategy information

The search strategy was written a priori by the authors, and used throughout the database search process.

Table 1: Search strategy for study III.

Overview	
Databases	Pubmed Scopus Web of Science Subject headings customized for each database. Duplicates between databases were removed in EndNote™(Clarivate™), v 20, software.
Search date	June 14th, 2021
Study Design	No restrictions concerning study design were applied
Limits	No date limit (included all studies until June 14th, 2021) No language limits was added to search strategy, but studies with languages other than English, French, Spanish and Portuguese were excluded in title and abstract analysis
Syntax Guide	
MeSH	Medical Subject Heading (PubMed Database)
*	After a word, a truncation symbol (wildcard) to retrieve plurals or varying endings
TITLE-ABS-KEY	Title, abstract and keywords (SCOPUS Database)

TS	Title and abstract (Web of Science Database)

PUBMED
("aged"[MeSH Terms] OR "aged"[Title/Abstract] OR "elder*"[Title/Abstract] OR "aged, 80 and over"[MeSH Terms] OR "older adult*"[Title/Abstract] OR "older person*"[Title/Abstract] OR "centenarian*"[Title/Abstract] OR "nonagenarian*"[Title/Abstract] OR "octogenarian*"[Title/Abstract])
("Guidelines as Topic"[MeSH Terms] OR "Guideline*"[Title/Abstract])
("Biomechanical Phenomena"[MeSH Terms] OR "Biomechanic*"[Title/Abstract] OR "movement analysis"[Title/Abstract] OR "movement assessment*"[Title/Abstract] OR "movement evaluation*"[Title/Abstract] OR "kinetic*"[Title/Abstract] OR "Kinematic*"[Title/Abstract] OR "task*"[Title/Abstract] OR "gait"[Title/Abstract] OR "sit-to-stand"[Title/Abstract] OR "climbing stair*"[Title/Abstract])

SCOPUS
TITLE-ABS-KEY("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*")
TITLE-ABS-KEY("Guideline*")
TITLE-ABS-KEY("Biomechanic*" OR "movement analysis" OR "movement assessment*" OR "movement evaluation*" OR "kinetic*" OR "Kinematic*" OR "task*" OR "gait" OR "sit-to-stand" OR "climbing stair*")

Web of Science
TS=("aged" OR "elder*" OR "older adult*" OR "older person*" OR "centenarian*" OR "nonagenarian*" OR "octogenarian*")
TS=("Guideline*")

TS=("Biomechanic*" OR "movement analysis" OR "movement assessment*" OR "movement evaluation*" OR "kinetic*" OR "Kinematic*" OR "task*" OR "gait" OR "sit-to-stand" OR "climbing stair*")

Appendix XV – Supplementary material of Study IV

Kinematic and Kinetic Gait Principal Component Domains in Older Adults with and without functional disability: a cross sectional study.

Table 1: Definitions of gait parameters included in the factor analysis. (Supplementary table S1)

Gait Outcome	Definition
Spatiotemporal Measures	
Step length (m)	Average distance, in meters, between the position of the right/left foot in the heel strike and the position of the left/right foot in the next heel strike. (Has-motion, 2024)
Step velocity (m/s)	The calculation involves determining the length of each step divided by the corresponding step time for both the right and left sides. (Has-motion, 2024)
Step time (s)	Average time, in seconds, between the right/left heel strike and the left/right heel strike (Has-motion, 2024)
Swing time (s)	Average time, in seconds, between the right/left toe-off and the right/left heel strike (Has-motion, 2024)
Stance time (s)	Average time, in seconds, between the right/left heel strike and the right/left toe-off (Has-motion, 2024)
Stride width (m)	Distance between proximal end position of the foot at ipsilateral heel strike to the proximal end position of the foot at the next ipsilateral heel strike. (Has-motion, 2024)
Joint Kinematics	
Sagittal/Frontal/Transverse Hip ROM (°)	Range of motion of Hip, Knee, and Ankle angle, in sagittal/ frontal/ tranverse plane, measured in degrees, obtained subtracting the minimum to the maximum value along the gait cycle.
Sagittal/Frontal/ Transverse Knee ROM (°)	
Sagittal/Frontal/ Transverse Ankle ROM (°)	
Peak Hip Extension (°)	Maximum value, in degrees, of hip extension, flexion and ankle plantar flexion along the gait cycle.
Peak Hip Flexion (°)	
Peak Ankle Plantar flexion (°)	
Sagittal/Frontal/ Transverse Hip Angle at HS (°)	Value, in degrees, of hip, knee and ankle sagittal/frontal/ transverse angles at the events of heel strike (HS) or toe-off (TO).
Sagittal/Frontal/ Transverse Hip Angle at TO (°)	
Sagittal/Frontal/ Transverse Knee Angle at HS (°)	

Sagittal/Frontal/ Transverse Knee Angle at TO (°)	
Sagittal/Frontal/ Transverse Ankle Angle at HS (°)	
Sagittal/Frontal/ Transverse Ankle Angle at TO (°)	
Variability Measures	
Step time variability (s) Stance time variability (s) Swing time variability (s) Step velocity variability (m/s) Step length variability (m)	The combined standard deviation of left and right steps was calculated by taking the square root of the mean variance of the left and right steps according to the formula: $SD_{Left\&Right}$= (Galna et al., 2013)
Asymmetry Measures	
Step Time Asymmetry (% GC) Swing Time Asymmetry (% GC) Stance Time Asymmetry (% GC) Step length asymmetry (% GC)	The comparison of the right side parameter to the left side parameter using the formula: *100 * |ln |* (Monaghan et al., 2021)
Kinetic measures	
Vertical GRF 2nd peak (BW)	Second maximum value of vertical ground reaction force (GRF), measured in Newtons (N), normalized to participant mass measured in kilograms (Kg) multiplied by acceleration due to gravity (9.81 m/s^2) (Boyer et al., 2017; Has-motion, 2024)
Anteroposterior GRF peak (BW)	Maximum value of antero-posterior ground reaction force (GRF), measured in Newtons (N), normalized to participant mass measured in kilograms (Kg) multiplied by acceleration due to gravity (9.81 m/s^2) (Boyer et al., 2012)
Ankle Peak Dorsiflexion Moment (Nm/Kg)	Moment of force equivalent to the sum of all moments of force acting across the ankle joint, normalized to participant mass measured in kilograms (Kg). (Gordon et al., 2014; Has-motion, 2024)
Sagittal Peak Ankle Power generation (W/Kg)	The joint power was computed by multiplying the joint moments (Nm/kg) and joint angular velocities (rad/s), normalized to participant mass measured in kilograms (Kg). (Has-motion, 2024)

Table 2: Replication of Lord and Colleagues Factor Analysis (Lord et al., 2013). Relevant item loadings (>0.7) in bold. (Supplmentary table S2)

KMO=0.647 and Bartlett's Test of Sphericity p<0.001

Gait Spatiotemporal Variable	Pace/ Rhythm	Variability	Asymmetry	Postural Control
Step time (s)	**0,943**	0.277	0.068	-0.051
Stance time (s)	**0.928**	0.304	0.031	-0.069
Swing time (s)	**0.862**	0.245	0.179	-0.034
Step velocity (m/s)	**-0.786**	-0.357	0.167	0.421
Step time variability (m/s)	0.415	**0.891**	0.024	0.001
Stance time variability (s)	0.417	**0.880**	0.027	-0.069
Step velocity variability (m/s)	0.012	**0.827**	-0.023	-0.216
Swing time variability (s)	0.445	**0.772**	0.059	0.001
Swing time asymmetry (s)	0.123	-0.152	**0.891**	-0.115
Step time asymmetry (s)	-0.083	-0.056	**0.848**	0.031
Stance time asymmetry (s)	0.098	0.384	**0.735**	-0.091
Step length asymmetry (m)	-0.186	-0.111	-0.255	0.643
Step length (m)	-0.286	-0.457	0.332	0.605
Step length variability (m)	-0.556	0.021	0.317	0.604
Stride width (m)	0.078	-0.007	-0.082	0.604
Variance explained (%)	43.65	16.13	10.88	8.64

Table 3: Complementary factor analysis including lower limb frontal and transverse ROM and positions at HS and TO. Relevant item loadings (>0.7) in bold. (Supplementary table S3)

KMO=0.535 and Bartlett's Test of Sphericity p<0,001

	PC1	PC2	PC3	PC4	PC5	PC6
Transverse Ankle Angle at TO	0.909	-0.046	0.009	-0.21	-0.114	0.019
Transverse Ankle Angle at HS	0.806	-0.196	-0.131	-0.329	-0.226	-0.051
Transverse Knee Angle at TO	-0.801	-0.437	-0.009	0.053	-0.17	0.139
Transverse Knee Angle at HS	-0.601	-0.471	-0.14	0.081	-0.008	0.433
Transverse Ankle ROM	0.594	0.267	0.367	0.313	-0.082	0.062
Transverse Hip Angle at HS	0.099	0.880	0.135	0.009	0.177	-0.192
Transverse Hip Angle at TO	0.221	0.872	-0.007	0.122	0.127	0.115
Frontal Knee Angle at TO	-0.106	0.836	-0.179	-0.018	-0.286	0.061
Frontal Knee Angle at HS	-0.07	0.588	-0.429	-0.148	-0.542	-0.119
Frontal Hip ROM	0.194	-0.127	0.866	-0.029	0.004	-0.036
Frontal Knee ROM	-0.029	0.152	0.646	-0.206	0.289	0.261
Transverse Knee ROM	-0.457	0.055	0.544	0.063	-0.055	-0.331
Frontal Ankle ROM	-0.106	-0.21	0.451	0.49	-0.124	-0.084
Frontal Ankle Angle at HS	-0.074	-0.01	-0.01	0.930	-0.049	0.025
Frontal Ankle Angle at TO	-0.223	0.14	-0.157	0.889	0.124	0.003
Frontal Hip Angle at TO	-0.064	0.115	-0.18	-0.069	0.882	0.013
Frontal Hip Angle at HS	-0.143	-0.099	0.348	0.069	0.753	-0.226
Transverse Hip ROM	-0.073	-0.022	0.036	0.003	-0.096	0.867
Variance explained (%)	22.89	16.28	14.96	10.34	8.14	6.58

Appendix XVI – Supplementary material of Study V

Table 1: Mean and standard deviation of Hip, Knee and Ankle position (P) and angular velocities (V) in X,Y,Z planes, at contact with step and leaving the step during ascend and descend stairs cycles in older adult without (ND) and with (D) disability. (Supplementary table S1)

					Ascend		Descend	
					ND	**D**	**ND**	**D**
Stair Cycle	Contact moment with step (HS)	Hip	X	P	71.8±11.6	71.0±10.9	30.8±11.9	29.2±9.0
				V	-48.0±23.8	-40.3±15.1	-72.2±36.2	-53.2±19.6
			Y	P	7.8±4.9	10.3±4.4	-0.6±3.5	-0.4±3.4
				V	18.7±22.0	10.3±20.5	8.4±19.5	13.3±14.2
			Z	P	-0.9±8,0	3.3±14.3	-7.4±9.2	-7.0±12.5
				V	13.9±15.9	10.7±11.5	-8.3±22.8	-16.2±22.8
		Knee	X	P	74.6±5.2	70.4±8.8	19.5±5.1	17.0±7.0
				V	-140.2±62.2	-89.1±42.9	6.7±51.8	29.8±37.4
			Y	P	7.9±5.2	8.3±10.5	-3.6±4.1	-4.0±4.2
				V	-27.4±31.3	-19.6±25.2	13.0±11.9	17.1±12.2
			Z	P	-16.5±7.5	-20.6±10.8	-18.4±8.3	-20.8±13.2
				V	19.1±20.7	14.9±20.9	27.0±30.6	46.7±27.2
		Ankle	X	P	-6.3±4.8	-7.8±5.4	-40.6±5.9	-40.1±6.4
			Y	P	10.2±4.6	10.4±5.2	6.5±4.9	5.6±6.3
				V	-35.4±36.1	-43.1±30.3	-62.9±34.8	-57.8±41.5
			Z	P	1.4±4.7	0.4±6.0	5.9±4.1	4.7±5.3
				V	-5.6±20.1	-10.3±13.4	11.4±17.7	5.3±23.0
	Leaving Step (TO)	Hip	X	P	34.7±12.7	30.4±11.4	35.2±12.5	36.6±11.7
				V	199.7±43.2	168.7±36.1	153.0±43.4	113.5±35.1
			Y	P	0.6±3.1	2.6±2.4	6.4±4.2	8.6±3.4
				V	2.3±25.8	-9.8±24.2	-52.3±19.4	-36.5±17.9
			Z	P	-0.4±7.5	-0.8±12.1	-0.5±7.3	0.9±12.1
				V	18.9±32.0	29.9±38.3	-24.8±27.7	-3.2±28.3
		Knee	X	P	58.4±11.6	49.7±12.7	84.8±6.4	85.6±10.8
				V	392.5±91.4	336.5±63.9	283.2±86.2	197.0±87.3
			Y	P	0.3±5.5	-1.7±9.1	6.5±5.4	6.0±10.0
				V	12.4±48.6	12.3±64.6	23.4±48.1	13.9±52.6
			Z	P	-15.4±6.3	-14.7±9.8	-16.5±5.9	-19.3±9.0
				V	-48.5±42.1	-57.1±47.9	-18.2±22.4	-10.1±28.8
		Ankle	X	P	-29.9±7.0	-30.6±5.8	0.3±5.8	-1.9±7.9
				V	128.0±87.0	84.9±79.4	-212.6±50.8	-160.0±58.8
			Y	P	7.6±4.1	8.5±5.8	11.1±5.3	12.8±5.6
				V	-13.5±30.2	2.8±25.2	-44.5±34.3	-44.1±32.7
			Z	P	5.6±4.4	5.9±6.2	0.3±4.2	-0.5±6.3
				V	-43.2±27.3	-37.2±19.2	13.8±22.5	10.6±20.5

Table 2: Mean and standard deviation of Hip, Knee and Ankle position (P) and angular velocities (V) in X,Y,Z planes, at contact with floor and leaving the floor during transitions Floor to Stairs (F-S) and Stairs-Floor (S-F) in older adult without (ND) and with (D) disability.(Supplementary table S2)

					Ascend		Descend	
					ND	**D**	**ND**	**D**
Transition Floor to Stairs and Stairs-Floor Cycles	Contact moment with floor	Hip	X	P	44.4±11.4	43.8±10.1	43.3±11.5	43.9±10.6
				V	-18.7±15.5	-16.8±14.0	-23.3±28.2	-17.8±11.3
			Y	P	5.7±3.3	5.9±3.6	5.4±2.9	6.4±3.4
				V	5.0±19.0	-3.5±11.9	7.2±21.3	-8.7±15.0
			Z	P	-1.8±8.6	0.6±12.5	-2.2±8.1	-1.3±12.8
				V	-2.4±20.3	-1.0±12.2	-12.3±23.2	-5.4±18.8
		Knee	X	P	15.5±5.9	14.3±5.7	13.2±5.7	13.1±6.4
				V	16.3±58.7	25.1±47.9	-74.4±116.8	-40.3±81.8
			Y	P	-4.1±4.0	-4.6±4.9	-4.2±3.6	-4.9±-9.6
				V	-2.0±13.0	-5.5±11.0	-11.5±20.5	-9.6±34.1
			Z	P	-18.4±7.6	-20.1±14.1	-20.5±7.7	-20.2±13.8
				V	2.7±34.4	-6.8±21.2	10.3±40.0	-8.8±28.9
		Ankle	X	P	-24.8±4.4	-26.6±6.1	-23.5±4.2	-25.6±6.2
				V	-53.7±23.1	-62.2±34.8	-30.7±39.2	-56.6±43.8
			Y	P	8.6±4.3	7.9±5.1	9.0±4.4	8.3±5.1
				V	-46.9±30.7	-42.4±24.0	-20.0±33.7	-33.1±37.8
			Z	P	5.1±4.20	3.2±6.0	4.6±3.7	3.1±6.5
				V	2.4±17.2	2.3±16.7	3.6±17.7	0.6±12.9
	Leaving the floor	Hip	X	P	20.9±10.8	20.6±11.2	18.6±11.4	17.1±10.4
				V	142.2±34.0	130.0±24.2	147.2±33.0	139.0±39.9
			Y	P	1.8±2.9	3.7±2.4	3.1±3.4	4.8±3.4
				V	-22.0±15.0	-18.7±18.0	-58.9±20.0	-43.3±24.2
			Z	P	-1.4±7.8	-1.6±11.3	-3.4±7.6	-3.3±11.9
				V	-2.9±28.0	9.6±34.4	-14.6±35.1	0.7±29.5
		Knee	X	P	47.9±7.3	46.7±9.5	68.3±7.8	67.0±9.3
				V	234.3±116.5	192.1±97.6	321.6±66.4	278.8±68.8
			Y	P	-2.0±4.8	-3.1±6.9	1.2±6.8	0.2±8.8
				V	7.7±40.2	-5.8±44.1	12.0±44.1	-0.0±57.8
			Z	P	-17.1±6.9	-18.3±11.3	-15.6±6.9	-17.0±9.6
				V	-13.6±23.9	-28.1±32.9	-19.4±32.7	-17.0±30.5
		Ankle	X	P	-22.7±5.6	-23.4±5.3	-10.5±8.4	-13.4±8.5
				V	-123.0±65.6	-89.9±42.4	-230.4±61.8	-168.0±63.1
			Y	P	9.4±4.0	9.4±5.4	10.6±4.9	12.0±5.8
				V	-26.1±32.4	-24.1±32.6	-47.5±41.1	-51.1±37.2
			Z	P	5.9±30.1	4.6±6.2	5.1±4.6	4.5±6.6
				V	4.7±10.3	-4.8±16.6	4.2±32.7	-10.9±30.1

Table 3: Mean and standard deviation of Range of motion (ROM) and range of angular velocity (ΔVelocity) during stair cycles and during transitions Floor to Stairs (F-S) and Stairs-Floor (S-F) in older adult without (ND) and with (D) disability. (Supplementary table S3)

	Joint	**Axis**	**ROM ΔVelocity**	**Ascend Stairs**		**Descend Stairs**	
				ND	**D**	**ND**	**D**
Stair Cycles	Hip	X	ROM	55.4 ±2.9	53.7±4.7	27.8±4.0	27.0±3.0
			ΔV	316.5±45.4	286.3±35.1	295.8±85.4	239.5±45.4
		Y	ROM	13.5±2.9	12.8±3.2	12.1±2.9	13.5±4.3
			ΔV	112.5±28.6	123.7±59.4	130.3±32.1	117.1±26.8
		Z	ROM	11.1±3.3	16.4±11.7	14.5±5.7	17.0±5.7
			ΔV	129.7±25.0	151.9±76.4	160.6±33.0	159.3±36.8
	Knee	X	ROM	85.4±6.9	83.8±4.7	83.5±4.8	83.0±4.0
			ΔV	651.1±112.3	587.0±83.8	690.6±138.0	570.7±97.2
		Y	ROM	10.1±2.5	12.2±9.7	13.8±5.4	14.4±7.5
			ΔV	165.3±44.1	165.1±74.5	160.3±53.0	153.2±70.4
		Z	ROM	15.1±4.2	20.6±11.3	15.0±6.5	16.3±6.9
			ΔV	168.8±29.8	198.4±95.1	189.0±41.2	181.6±50.5
	Ankle	X	ROM	34.1±4.6	32.2±4.6	58.5±5.8	58.4±5.7
			ΔV	397.3±60.9	358.9±49.8	559.7±73.7	492.1±79.6
		Y	ROM	10.8±2.3	11.0±2.2	12.4±2.8	14.4±3.3
			ΔV	184.7±45.8	175.2±47.2	194.9±40.8	186.1±30.7
		Z	ROM	12.8±2.7	12.1±3.2	12.6±2.5	12.1±2.6
			ΔV	146.5±39.6	126.4±35.7	141.0±30.6	125.2±25.6
Transition Floor to Stairs and Stairs-Floor Cycles	Hip	X	ROM	54.4±4.5	54.0±5.1	46.1±7.0	46.3±6.0
			ΔV	329.4±59.1	297.7±47.4	296.6±63.6	274.7±50.1
		Y	ROM	11.2±2.3	10.1±2.4	11.6±3.0	10.9±2.3
			ΔV	118.6±28.7	118.0±30.1	145.0±37.0	135.0±27.2
		Z	ROM	10.8±2.6	13.2±7.9	13.8±6.5	15.5±5.3
			ΔV	141.9±30.1	142.8±58.3	174.3±37.9	178.0±48.5
	Knee	X	ROM	70.2±6.6	67.7±5.7	75.5±4.4	73.4±4.4
			ΔV	658.5±122.5	575.0±91.6	750.6±130.3	652.7±114.1
		Y	ROM	11.8±3.3	14.1±8.4	12.1±5.7	12.8±6.6
			ΔV	139.7±45.0	138.0±69.5	164.3±52.4	165.5±74.2
		Z	ROM	13.6±4.1	18.1±8.2	17.6±7.2	19.3±6.1
			ΔV	164.4±37.6	180.9±61.4	201.5±55.4	194.3±52.9
	Ankle	X	ROM	31.3±4.4	30.9±3.1	32.2±4.1	32.1±4.2
			ΔV	406.8±60.4	365.3±46.9	482.1±69.1	429.7±62.5
		Y	ROM	11.0±2.2	10.9±1.7	11.6±3.0	11.9±2.1
			ΔV	167.2±36.9	153.2±26.6	189.4±42.0	176.6±33.4
		Z	ROM	12.5±2.9	11.3±2.4	13.7±3.0	13.3±2.9
			ΔV	147.5±47.5	125.7±36.6	160.9±47.6	142.7±35.5

Table 4:Mean and standard deviation of Center of mass displacement and velocity range(ΔVelocity) during transitions Floor to Stairs (F-S) and Stairs-Floor (S-F) in older adult without (ND) and with (D) disability. (Supplementary table S4)

Sub-task		**Axis**	**Ascend Stairs**		**Descend Stairs**	
			ND	**D**	**ND**	**D**
Stair Cycle	X	Displacement	0.05±0.01	0.04±0.01	0.05±0.01	0.04±0.01
		ΔVelocity	0.22±0.05	0.19±0.04	0.31±0.06	0.30±0.05
	Y	Displacement	0.63±0.02	0.62±0.01	0.26±0.03	0.26±0.04
		ΔVelocity	0.30±0.05	0.29±0.05	0.35±0.05	0.35±0.04
	Z	Displacement	0.30±0.01	0.30±0.01	0.30±0.01	0.30±0.01
		ΔVelocity	0.56±0.09	0.57±0.08	0.51±0.09	0.56±0.10
Transition F-S and S-F	X	Displacement	0.04±0.01	0.04±0.01	0.05±0.01	0.04±0.01
		ΔVelocity	0.19±0.05	0.19±0.04	0.25±0.06	0.22±0.06
	Y	Displacement	0.91±0.04	0.90±0.03	0.97±0.07	1.02±0.07
		ΔVelocity	0.61±0.11	0.67±0.08	0.38±0.06	0.38±0.07
	Z	Displacement	0.22±0.01	0.22±0.01	0.07±0.01	0.08±0.01
		ΔVelocity	0.60±0.1	0.65±0.08	0.66±0.11	0.72±0.1

Appendix XVII – Supplementary material of Study VI

Supplementary material

Sit-TS and Stand-TS phases

The Sit-TS and Stand-TS tasks were divided into 4 phases each, according previous literature on older adults movement analysis (Lin & Lee, 2022) (Figure 1). The Sit-TS was divided into flexion, momentum transfer, extension and stabilization (Lin & Lee, 2022). The flexion or initiation phase started from the first deflection of vertical GRF following the start of the acquisition time (Piano et al., 2020) and ended at seat off event, corresponding to the maximum positive anteroposterior GRF following initiation (Buckley et al., 2009). The momentum transfer phase started at seat off and ended at maximum peak vertical center of mass velocity (Buckley et al., 2009). The third phase, extension, begin at maximum peak vertical COM velocity and ended at extension that was defined as the instant when the sagittal knee angle reaches the minimum values, as the maximum point of knee extension (Alcock et al., 2015). The stabilization phase started at the end of the previous and ended at a stabilization event. Although the stabilization point has been defined by visual inspection in literature (Piano et al., 2020), to standardize to all participants, in this study was defined as the instant the vertical force reached the average value calculated in the first 50 frames after the extension (standing baseline).

The Stand-TS task was divided into initiation, flexion, momentum transfer and extension (Lin & Lee, 2022). The start of sitting down was defined by the beginning of knee flexion, which was defined as the instant where sagittal knee angle reached a value higher than the average value of the standing baseline plus two times the standard deviation. The initiation phase started from the previous event and ended at minimum peak vertical CoM velocity. This event initiated the flexion phase, that ended at the maximum peak vertical GRF (Lin & Lee, 2022). The momentum transfer phase started at the end of the previous phase and ended at seat-on event, corresponding to minimum anteroposterior GRF. The extension phase began at seat-on and ended at instant where the vertical GRF assumed a value lower than the average value obtained during the first 50 frames after seat-on plus two times the standard deviation.

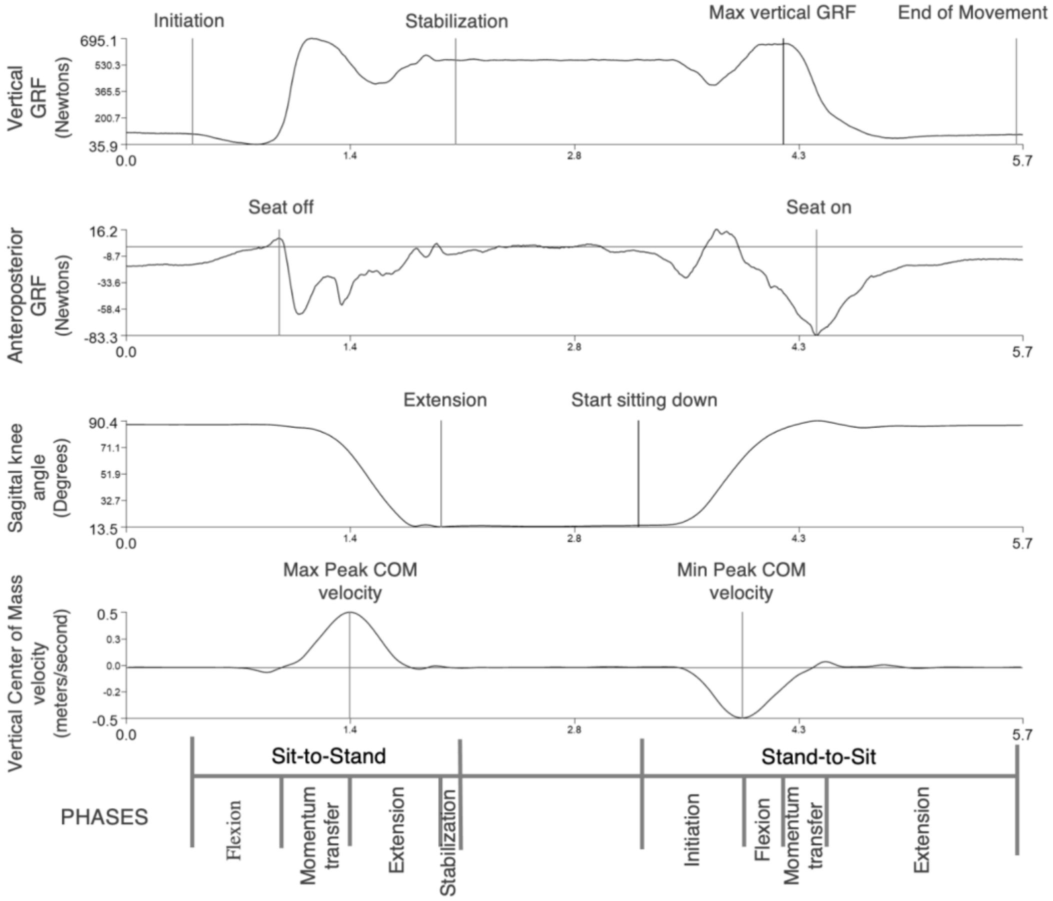

Figure 1: Sit-to-Stand and Stand-to-Sit phases and respective events definition according vertical and anteroposterior Ground Reaction Force (GRF), sagittal knee angle and vertical center of mass velocity. (Supplementary figure S1)

Principal Component Models of Sit-TS phases

Table 1: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Flexion phase of Sit-TS task. Kaiser-Meyer-Olkin value of 0.743 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S1)

Flexion Phase Sit-TS

Principal Component	1	2	3	4	5	6
Explained variance (%)	37.67	15.73	8.03	5.97	5.21	4.12
Sagittal ankle ROM	**0.871**	-0.053	0.199	0.09	-0.029	0.072
Frontal ankle joint velocity range	**0.860**	-0.04	-0.048	0.202	0.054	0.155
Transverse ankle joint velocity range	**0.849**	0.191	0.064	0.202	-0.015	-0.019
Transverse ankle ROM	**0.832**	0.117	-0.096	0.12	0.066	0.231
Transverse knee ROM	0.734	0.078	0.11	-0.013	0.31	0.059
Frontal ankle ROM	0.731	-0.115	-0.048	0.059	0.368	0.179
Frontal knee joint velocity range	0.713	0.207	0.366	0.076	0.107	-0.226
Sagittal ankle joint velocity range	0.711	-0.008	0.186	0.398	0.022	-0.133
Sagittal knee joint velocity range	0.634	0.54	0.078	0.033	-0.095	0.251
Frontal hip joint velocity range	0.025	**0.931**	0.182	0.094	0.092	0.096
Transverse hip ROM	0.141	**0.904**	0.133	0.061	0.2	0.137
Frontal trunk ROM	-0.027	**0.901**	0.123	-0.008	0.262	0.128
Frontal trunk joint velocity range	-0.052	**0.887**	0.188	0.06	0.093	0.045
Sagittal trunk joint velocity range	-0.023	0.514	0.283	0.462	0.114	-0.123
Frontal knee ROM	0.288	0.567	0.122	0.265	-0.021	0.33
Transverse knee joint velocity range	0.333	0.503	0.378	0.169	-0.167	0.056
Transverse trunk joint velocity range	0.055	0.205	**0.887**	0.16	-0.004	0.072
Transverse hip joint velocity range	0.122	0.134	**0.866**	0.075	0.207	-0.006
Transverse trunk ROM	0.002	0.292	0.78	0.134	0.211	0.189
Frontal hip ROM	0.231	0.254	0.555	0.07	0.471	0.038
Sagittal hip ROM	0.401	0.11	0.118	0.771	0.084	0.15
Ap CoM velocity range	0.364	0.103	0.13	0.739	0.387	-0.023
Sagittal hip joint velocity range	0.037	0.592	0.169	0.64	0.294	0.005
AP CoM displacement	0.397	0.047	0.227	0.594	0.307	0.403

Vertical CoM velocity range	0.088	0.24	0.098	0.313	**0.812**	0.033
Vertical CoM displacement	0.21	0.014	0.287	0.332	0.708	0.145
Sagittal trunk ROM	0.082	0.467	0.223	0.009	0.668	0.09
ML CoM displacement	0.006	0.113	0.046	0.043	0.069	**0.86**
Sagittal knee ROM	0.345	0.364	0.14	0.004	0.064	0.568
ML CoM velocity range	0.169	0.245	0.5	0.147	0.194	0.502

Table 2: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Momentum transfer phase of Sit-TS task. Kaiser-Meyer-Olkin value of 0.545 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S2)

Momentum transfer phase Sit-TS

Principal Component	1	2	3	4	5	6	7	8	9
Explained variance (%)	23.37	12.91	9.82	9.08	5.95	5.31	3.98	3.79	3.62
Sagittal knee joint velocity range	**0.924**	0.003	0.151	-0.118	-0.029	-0.008	-0.015	-0.055	0.08
Vertical CoM velocity	**0.864**	0.175	-0.051	0.099	-0.112	0.145	-0.066	0.094	-0.156
Sagittal hip joint velocity range	0.769	-0.121	0.057	0.401	0.298	0.008	-0.072	0.076	-0.224
Vertical CoM displacement	0.703	0.203	0.109	0.1	-0.233	0.135	0.45	-0.008	0.258
Sagittal ankle joint velocity range	0.682	-0.102	0.285	-0.007	0.022	-0.013	-0.112	0.33	0.348
Sagittal hip ROM	0.625	-0.149	0.21	0.352	0.254	-0.038	0.442	-0.145	0.016
Frontal trunk ROM	-0.157	**0.844**	0.115	-0.004	-0.017	-0.003	-0.064	-0.015	0.109
Transverse trunk ROM	0.079	**0.824**	-0.042	0.146	-0.003	-0.015	0.019	-0.002	0.033
Transverse trunk joint velocity range	0.105	0.629	0.092	0.024	0.042	0.118	0.17	0.159	0.174
Frontal trunk joint velocity range	-0.167	0.627	0.072	-0.07	0.2	0.398	-0.149	0.197	-0.163
Frontal hip ROM	0.187	0.577	0.08	0.132	-0.253	0.483	0.163	0.309	-0.138
Transverse hip joint velocity range	0.324	0.485	0.181	0.424	0.028	0.313	-0.054	0.171	0.027
Frontal ankle ROM	0.275	0.406	-0.146	0.533	-0.054	-0.049	0.205	0.393	0.055
Transverse knee joint velocity range	0.124	-0.009	0.787	0.225	0.187	-0.015	-0.229	0.138	0.056
Transverse hip ROM	0.224	0.35	0.733	0.107	0.111	-0.057	0.249	-0.229	-0.058
Frontal knee ROM	-0.069	-0.085	0.728	-0.289	-0.317	0.097	0.061	0.044	0.08
Frontal hip joint velocity range	0.1	0.301	0.691	0.387	0.274	0.139	-0.055	0.041	-0.075
Frontal knee joint velocity range	0.415	-0.013	0.614	0.024	0.181	0.301	-0.198	-0.138	0.091
Sagittal ankle ROM	0.148	-0.047	0.113	**0.832**	0.196	-0.108	-0.096	0.108	0.207
AP CoM displacement	-0.006	0.226	0.178	0.788	-0.316	0.064	0.168	0.146	-0.067
Transverse ankle ROM	-0.036	0.191	0.282	0.091	0.708	0.136	0.138	0.203	0.07
Tranverse ankle joint velocity range	0.357	0.057	0.341	0.127	0.659	-0.102	-0.222	0.126	0.08
AP CoM velocity range	0.207	0.165	0.228	0.227	-0.626	-0.05	-0.216	0.231	0.073
Transverse knee ROM	0.176	-0.059	0.226	-0.083	-0.01	0.753	0.086	-0.247	0.187
Sagittal trunk joint velocity range	-0.03	0.406	-0.062	-0.015	0.108	0.746	0.033	0.143	0.113
ML CoM displacement	-0.06	0.028	-0.163	0.023	0.136	0.023	0.755	0.121	0.065
Sagittal knee angle	0.308	0.036	0.211	-0.464	-0.257	0.235	0.523	-0.15	0.259
ML CoM velocity range	-0.094	0.085	-0.003	0.117	-0.054	0.057	0.452	0.626	-0.227

Frontal ankle joint velocity range	0.161	0.216	-0.004	0.228	0.144	-0.054	-0.063	0.772	0.100
Sagittal trunk ROM	0.013	0.194	0.031	0.1	0.043	0.186	0.096	-0.023	**0.859**

Table 3: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Extension phase of Sit-TS task. Kaiser-Meyer-Olkin value of 0.586 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S2)

Extension phase Sit-TS

Principal Component	1	2	3	4	5	6	7	8
Explained variance (%)	21.70	13.71	10.02	9.07	7.28	5.82	5.02	3.67
Sagittal knee joint velocity range	**0.925**	0.132	-0.079	0.069	-0.179	-0.15	-0.084	-0.082
Sagittal ankle joint velocity range	**0.904**	0.12	-0.167	-0.011	-0.183	-0.111	-0.015	-0.001
Transverse ankle joint velocity range	**0.828**	0.01	-0.043	-0.05	-0.222	0.07	0.199	0.041
Sagittal hip joint velocity range	0.779	-0.126	0.416	0.12	0.046	-0.035	-0.085	-0.166
Vertical CoM velocity	0.763	0.369	0.219	0.245	0.036	-0.139	0.043	-0.122
Frontal ankle joint velocity	0.718	0.062	0.27	-0.083	0.015	0.283	0.18	-0.255
Transverse hip joint velocity range	0.704	-0.182	0.046	0.066	0.434	-0.014	0.037	0.265
Frontal knee joint velocity range	0.654	0.122	-0.142	-0.001	0.059	-0.032	0.166	0.514
Frontal hip joint velocity range	0.647	-0.197	-0.116	0.158	0.375	0.004	0.303	0.132
Transverse knee joint velocity range	0.529	-0.26	0.011	-0.149	0.467	-0.116	-0.209	0.395
Sagittal knee ROM	0.145	**0.915**	0.1	0.002	-0.087	-0.079	0.047	0.087
Sagittal ankle ROM	0.311	0.759	-0.259	-0.058	-0.242	-0.112	0.054	0.176
Vertical CoM displacement	-0.209	0.725	0.289	0.215	0.244	0.17	0.093	0.066
Sagittal trunk ROM	-0.275	0.555	-0.081	0.456	0.231	0.251	-0.208	0.049
Ap CoM displamencent	0.032	-0.008	**0.883**	0.21	0.11	0.115	0.073	0.011
AP CoM velocity range	0.19	-0.1	0.771	0.199	-0.075	0.117	-0.124	-0.181
Sagittal hip ROM	-0.119	0.314	0.753	-0.121	0.174	0.142	0.184	0.153
Sagittal trunk joint velocity range	0.031	0.14	0.178	**0.847**	-0.033	-0.026	-0.063	-0.245
Transverse trunk joint velocity range	0.144	0.033	0.248	0.752	-0.286	-0.174	0.098	-0.006
Frontal trunk joint velocity range	-0.061	-0.217	-0.028	0.687	0.101	0.233	0.391	0.149
Transverse trunk ROM	0.193	0.217	0.025	0.583	0.035	0.435	-0.046	0.281
Transverse hip ROM	-0.016	0.034	0.045	-0.024	0.764	-0.057	0.358	-0.01
Transverse knee ROM	-0.117	0.018	0.114	-0.083	0.747	0.014	-0.125	0.151
ML CoM velocity range	0.025	0	0.174	0.086	0.09	**0.855**	0.014	-0.194
ML CoM displacement	-0.206	-0.039	0.154	-0.029	-0.151	0.756	0.065	0.119
Transverse ankle ROM	0.168	0.302	-0.294	0.34	-0.017	0.361	0.178	0.224

Frontal hip ROM	0.219	-0.033	-0.101	0.252	0.129	-0.071	0.735	0.002
Frontal trunk ROM	-0.069	0.054	0.286	-0.009	-0.046	0.126	0.65	0.244
Frontal ankle ROM	0.212	0.322	-0.056	-0.149	0.038	0.099	0.514	-0.309
Frontal knee ROM	-0.074	0.245	-0.015	-0.017	0.191	0.01	0.074	0.759

Table 4: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Stabilization phase of Sit-TS task. Kaiser-Meyer-Olkin value of 0.842 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S4)

Stabilization phase Sit-TS

Principal Component	1	2	3	4	5
Explained variance (%)	60.06	9.84	6.73	4.73	4.23
Transverse knee joint velocity range	**0.925**	0.102	0.229	0.138	0.167
Transverse hip ROM	**0.921**	0.238	0.157	0.095	0.189
Transverse knee ROM	**0.901**	0.245	0.168	0.074	0.218
Transverse hip joint velocity range	**0.881**	0.153	0.313	0.189	0.083
Frontal knee ROM	**0.833**	0.204	0.24	0.078	0.266
Frontal trunk ROM	0.668	0.284	0.397	0.312	0.154
Sagittal trunk ROM	0.222	**0.878**	0.149	0.19	0.113
Vertical CoM displacement	0.168	**0.861**	0.095	0.297	0.203
Vertical CoM velocity	0.236	0.776	0.455	0.181	0.224
ML CoM velocity	0.27	0.727	0.285	0.123	0.021
Sagittal knee ROM	0.148	0.684	0.432	0.01	0.466
Sagittal hip ROM	0.17	0.676	0.254	0.164	0.48
Sagittal hip joint velocity range	0.254	0.598	0.485	0.146	0.43
ML CoM displacement	0.059	0.595	0.326	0.105	0.043
Sagittal ankle joint velocity range	0.281	0.325	0.792	0.258	0.207
Transverse ankle joint velocity range	0.333	0.255	0.771	0.302	0.078
AP CoM velocity range	0.325	0.495	0.702	0.229	0.11
Frontal ankle joint velocity range	0.201	0.277	0.65	0.072	0.552
Sagittal ankle ROM	0.335	0.277	0.636	0.367	0.357
Transverse ankle ROM	0.359	0.49	0.613	0.108	0.148
AP CoM displacement	0.301	0.426	0.586	0.396	0.244
Transverse trunk joint velocity range	0.057	0.121	0.18	**0.926**	0.055
Frontal trunk joint velocity range	0.389	0.158	0.084	0.742	0.372
Sagittal trunk joint velocity range	0.21	0.438	0.365	0.727	0.018
Transverse trunk ROM	0.11	0.288	0.551	0.693	0.053
Sagittal knee joint velocity range	0.209	0.299	0.224	0.029	**0.838**

Frontal knee joint velocity range	0.515	-0.017	0.164	0.247	0.751
Frontal hip ROM	0.512	0.441	-0.008	0.153	0.54
Frontal hip joint velocity range	0.442	0.251	0.403	0.398	0.466
Frontal ankle ROM	0.339	0.384	0.498	0.212	0.427

Principal Component Models of Stand-TS phases

Table 5: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Initiation phase of Stand-TS task. Kaiser-Meyer-Olkin value of 0.588 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S5)

Initiation phase Stand-TS

Principal component	1	2	3	4	5	6	7	8	9	10
Variance explained (%)	24.36	11.14	9.35	7.85	6.01	5.59	4.89	4.16	3.53	3.42
AP CoM velocity	**0.879**	0.104	-0.055	0.052	0.085	-0.063	-0.037	0.156	-0.006	0.081
Sagittal hip velocity range	**0.871**	0.196	-0.109	0.066	-0.052	0.265	-0.013	0	-0.017	0.028
Vertical CoM velocity	0.774	0.2	0.228	0.07	0.084	0.34	0.19	-0.071	-0.112	0.138
Sagittal knee velocity range	0.669	0.175	0.293	0.054	-0.075	0.553	0.066	0.004	0.007	-0.083
AP CoM displacement	0.597	0.073	-0.015	0.25	0.038	-0.079	0.221	0.423	0.078	0.042
Frontal trunk ROM	0.459	-0.151	0.013	0.332	0.344	0.043	0.017	-0.091	0.229	-0.445
Transverse knee velocity range	0.138	**0.912**	-0.01	0.022	0.022	0.175	-0.115	-0.119	-0.135	-0.076
Transverse hip velocity range	0.1	**0.863**	0.059	0.01	0.043	0.069	0.017	-0.004	0.007	0.177
Frontal hip velocity range	0.344	0.734	0.001	0.032	-0.023	0.286	-0.049	-0.086	-0.007	0.076
Transverse knee ROM	-0.036	0.639	-0.026	0.171	0.002	-0.115	-0.033	0.382	0.043	-0.459
Transverse hip ROM	-0.062	0.604	-0.037	0.276	-0.036	-0.158	-0.099	0.185	0.449	-0.047
Frontal knee velocity range	0.382	0.571	0.393	-0.193	0.103	0.222	0.084	0.028	0.208	0.106
Sagittal ankle ROM	-0.141	0.026	**0.907**	0.016	0.063	0.178	0.033	0.044	0.115	0.055
Sagittal knee ROM	0.243	0.026	**0.86**	0.186	0.071	0.026	0.164	0.186	-0.058	-0.009
Frontal knee ROM	0.047	0.433	0.444	-0.149	0.049	-0.281	0.326	-0.071	0.412	0.026
ML CoM velocity	0.142	0.12	0.052	**0.825**	0.186	0.216	0.159	-0.184	0.068	0.087
ML CoM displacement	0.103	-0.003	0.082	0.784	-0.011	0.096	0.067	0.009	0.222	-0.069
Sagittal hip ROM	0.537	0.128	0.213	0.539	0.034	-0.193	0.138	0.318	-0.252	0.089
Transverse trunk velocity range	-0.064	0.006	0.132	0.072	**0.853**	-0.015	-0.128	0.024	-0.14	0.121
Transverse trunk ROM	0.028	0.072	0.112	-0.001	0.757	0.047	0.304	-0.16	0.004	-0.212
Frontal trunk velocity range	0.113	0.017	-0.042	0.07	0.751	0.043	-0.02	0.222	0.299	-0.034
Sagittal ankle velocity range	0.159	0.294	0.257	0.156	0.043	0.7	0.013	0.068	0.071	-0.009
Frontal ankle velocity range	0.317	0.006	-0.048	0.022	0.124	0.576	0.301	0.492	-0.023	0.088
Transverse ankle velocity range	0.107	0.168	-0.227	0.385	0.092	0.564	-0.343	0.115	0.271	0.184

Sagittal trunk ROM	0.098	-0.14	0.223	0.163	-0.004	0.035	**0.840**	0.015	0.125	-0.101
Vertical CoM displacement	0.003	0.023	0.503	0.383	0.19	-0.16	0.512	0.203	-0.274	0.227
Sagittal trunk velocity range	0.33	-0.028	-0.325	0.158	0.447	0.231	0.489	0.057	0.049	0.261
Frontal ankle ROM	0.131	-0.049	0.244	-0.143	0.038	0.167	-0.035	**0.826**	0.047	0.042
Transverse ankle ROM	-0.061	-0.006	0.051	0.199	0.087	0.127	0.081	0.019	0.79	0.108
Frontal hip ROM	0.371	0.095	0.131	0.147	-0.028	0.067	-0.058	0.109	0.308	0.653

Table 6: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Flexion phase of Stand-TS task. Kaiser-Meyer-Olkin value of 0.747 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S6).

Flexion phase Stand-TS

Principal component	1	2	3	4	5	6	7	8
Variance explained (%)	38.68	11.53	6.76	5.34	5.14	4.79	3.59	3.47
Transverse knee velocity range	**0.903**	0.042	-0.002	-0.143	0.032	-0.09	0.251	0.037
Frontal hip velocity range	**0.881**	0.156	-0.011	-0.118	0.132	-0.046	0.193	0.071
Frontal knee velocity range	**0.846**	-0.01	0.25	0.064	0.21	0.082	-0.068	0.095
Transverse hip ROM	0.778	0.088	0.005	0.246	0.032	0.251	0.226	0.006
Transverse hip velocity range	0.651	0.209	0.233	0.199	0.201	0.33	-0.009	-0.008
Transverse ankle velocity range	0.543	0.088	0.268	0.214	0.347	0.052	-0.299	0.253
Sagittal trunk velocity range	-0.033	0.775	0.229	0.046	0.157	0.21	-0.177	0.06
Frontal trunk velocity range	0.009	0.743	-0.002	0.156	0.088	0.128	-0.175	0.256
Vertical CoM velocity	0.323	0.669	0.145	0.096	0.424	0.133	0.261	0.171
Sagittal hip velocity range	0.39	0.643	0.298	0.078	0.177	-0.07	0.265	0.071
Transverse trunk velocity range	0.027	0.556	0.062	0.302	-0.008	0.356	-0.045	0.045
Vertical CoM displacement	0.298	0.467	0.379	0.431	0.194	0.253	0.393	0.203
ML CoM displacement	0.073	0.075	0.792	0.043	0.071	0.145	-0.016	0.141
ML CoM velocity	0.094	0.114	0.724	0.097	0.25	0.176	0.167	0.314
Transverse trunk ROM	0.038	0.486	0.609	0.292	-0.09	0.289	0.149	-0.11
Sagittal hip ROM	0.351	0.466	0.591	0.244	0.062	-0.094	0.268	0.112
AP CoM displacement	0.25	0.48	0.554	-0.023	0.12	0.005	0.385	0.262
Sagittal ankle ROM	-0.08	0.154	0.055	**0.886**	0.181	-0.012	0.125	0.231
Sagittal knee ROM	0.196	0.39	0.189	0.725	0.172	0.164	0.346	0.093
Transverse ankle ROM	0.138	0.14	0.574	0.601	0.14	0.253	-0.146	-0.005
Sagittal ankle velocity range	0.271	0.118	0.012	0.24	**0.853**	-0.034	-0.038	0.148
Sagittal knee velocity range	0.376	0.325	0.094	0.143	0.778	-0.017	-0.02	-0.045
AP CoM velocity	-0.074	0.051	0.428	-0.018	0.648	0.216	0.267	0.141
Frontal trunk ROM	-0.037	0.123	-0.011	0.029	-0.077	0.768	0.066	0.354
Frontal hip ROM	0.125	0.228	0.345	0.142	0.073	0.72	0.111	0.025
Sagittal trunk ROM	0.3	0.206	0.319	0.015	0.195	0.603	0.176	0.114
Frontal knee ROM	0.442	-0.212	0.06	0.134	0.025	0.117	0.674	0.123
Transverse knee ROM	0.17	0.023	0.256	0.244	0.047	0.249	0.569	-0.241

Frontal ankle ROM	0.051	0.229	0.282	0.174	0.045	0.241	0.034	**0.800**
Frontal ankle velocity range	0.26	0.229	0.216	0.168	0.238	0.215	-0.063	0.726

Table 7: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Momentum transfer phase of Stand-TS task. Kaiser-Meyer-Olkin value of 0.666 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. . (Supplementary table S7).

Momentum transfer phase Stand-TS

Principal component	1	2	3	4	5	6	7	8
Variance explained (%)	30.32	10.60	9.93	7.48	5.96	5.02	4.30	3.49
Vertical CoM displacement	**0.862**	-0.054	-0.005	0.013	-0.09	0.15	0.329	0.059
Sagittal knee ROM	**0.808**	-0.01	-0.005	0.12	0.039	0.083	0.453	-0.031
Transverse knee ROM	0.76	0.034	0.018	0.045	-0.096	-0.195	0.005	0.039
Sagittal hip ROM	0.736	0.199	0.134	0.089	0.215	0.16	0.027	0.174
Sagittal trunk ROM	0.696	0.199	0.177	0.159	0.222	0.232	-0.247	0.071
Frontal knee ROM	0.632	0.133	0.433	0.168	-0.142	0.042	-0.12	0.228
Frontal ankle velocity range	-0.091	**0.875**	0.026	0.145	0.013	0.2	-0.045	0.092
Frontal ankle ROM	0.035	**0.844**	-0.021	0.189	0.04	-0.034	0.134	0.117
Sagittal ankle ROM	0.135	0.641	0.134	0.034	-0.043	0.023	0.429	0.39
Sagittal ankle velocity range	0.469	0.614	-0.077	0.026	0.031	0.259	0.438	-0.093
Frontal knee velocity range	0.21	0.576	0.323	0.291	0.18	0.222	-0.147	0.162
Transverse ankle velocity range	0.401	0.499	0.326	0.282	-0.03	0.381	-0.089	-0.14
Transverse ankle ROM	0.441	0.471	0.105	0.353	-0.166	-0.120	0.325	-0.122
Frontal hip velocity range	0.071	0.011	**0.926**	0.024	0.285	0.049	0.062	0.041
Transverse knee velocity range	0.067	0.125	**0.924**	0.021	-0.08	0.103	-0.039	-0.052
Transverse hip ROM	0.579	-0.016	0.631	0.147	0.083	0.013	0.048	0.059
Transverse trunk ROM	0.147	0.224	-0.006	0.748	0.167	0.107	-0.036	0.068
ML CoM velocity	0.127	0.133	0.065	0.662	0.166	-0.038	0.279	0.104
Frontal hip ROM	0.158	0.37	0.078	0.647	0.076	0.15	0.075	0.087
Transverse trunk velocity range	-0.112	-0.311	-0.059	0.504	0.058	0.472	0.056	0.239
Sagittal trunk velocity range	0.036	0.047	0.068	0.101	**0.921**	0.136	-0.073	0.069
Frontal trunk velocity range	-0.1	-0.042	0.079	0.161	**0.916**	-0.015	-0.005	0.098
Frontal trunk ROM	0.453	0.126	0.118	0.478	0.556	0.061	-0.053	0.009
Vertical CoM velocity	0.088	0.217	0.075	0.155	0.008	**0.820**	0.078	0.002
Sagittal knee velocity range	0.015	0.2	0.003	0.04	0.078	0.664	0.595	-0.142
Sagittal hip velocity range	0.33	0.091	0.383	0.021	0.287	0.627	-0.256	0.198
AP CoM velocity	0.187	0.118	-0.01	0.213	-0.123	0.035	0.789	0.187

ML CoM displacement	0.149	0.155	-0.172	0.105	0.299	-0.084	0.179	0.681
AP CoM displacement	0.295	0.291	0.275	0.361	-0.026	0.135	-0.124	0.648
Frontal hip velocity range	-0.049	0.051	0.308	0.437	0.02	0.319	0.154	0.424

Table 8: Principal component model of trunk, hip, knee and ankle range of motion (ROM), joint velocity range in sagittal, frontal and transverse planes, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Momentum transfer phase of Stand-TS task. Kaiser-Meyer-Olkin value of 0.656 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S8).

Extension phase Stand-TS

Principal component	1	2	3	4	5	6	7
Variance explained (%)	30.84	15.92	8.30	8.07	6.00	4.31	3.97
Sagittal trunk velocity range	**0.949**	-0.028	0.019	-0.082	-0.001	-0.048	-0.004
Sagittal hip velocity range	**0.908**	0.102	0.119	-0.076	0.217	0.061	0.05
Frontal trunk velocity range	**0.882**	0.346	-0.072	-0.148	0.037	0.109	0.026
Sagittal trunk ROM	0.778	-0.026	0.181	0.196	0.146	0.032	0.261
Transverse trunk ROM	0.687	0.22	0.177	-0.018	-0.018	0.329	0.277
Transverse trunk velocity range	0.64	0.032	0.13	-0.066	-0.007	0.465	-0.076
Transverse hip ROM	0.176	0.778	0.133	-0.008	0.077	0.305	0.149
Frontal knee ROM	-0.12	0.747	0.364	0.136	-0.077	0.049	0.051
Frontal trunk ROM	0.363	0.694	-0.031	0.013	0.059	0.017	0.264
Transverse knee velocity range	0.206	0.646	0.094	0.191	0.292	0.223	-0.334
Frontal hip velocity range	0.575	0.598	-0.047	-0.034	0.256	0.376	-0.035
Sagittal knee ROM	-0.038	0.525	-0.182	0.388	0.178	-0.057	0.408
Sagittal hip ROM	0.101	0.094	0.778	-0.003	0.058	0.003	-0.092
Frontal ankle ROM	-0.052	0.005	0.722	0.428	-0.026	0.078	0.078
AP CoM displacement	0.273	0.257	0.706	0.206	0.066	0.237	0.306
AP CoM velocity	0.128	0.179	0.647	0.103	0.416	0.315	0.066
Vertical CoM displacement	0.309	-0.259	0.477	-0.008	0.404	0.055	0.329
Transverse ankle ROM	-0.070	0.06	0.029	**0.897**	0.015	0.05	-0.093
Frontal ankle velocity range	-0.084	0.049	0.39	**0.809**	0.087	0.079	-0.021
Transverse ankle velocity range	-0.005	0.147	0.011	0.681	0.474	0.280	-0.206
Transverse knee ROM	-0.058	0.163	0.272	0.508	0.148	0.505	0.183
Vertical CoM velocity	0.133	0.001	0.146	0.011	**0.926**	0.102	0.074
Sagittal knee velocity range	0.098	0.182	0.051	0.216	**0.894**	-0.001	0.027
Frontal hip ROM	0.216	0.214	0.154	0.171	-0.031	0.781	0.222
Transverse hip velocity range	0.522	0.18	0.104	0.073	0.308	0.653	-0.138
Frontal knee velocity range	0.102	0.206	0.026	0.319	0.531	0.551	-0.264
ML CoM displacement	0.203	0.231	0.249	-0.014	0.031	0.088	0.648
Sagittal ankle velocity range	-0.033	0.062	0.35	0.408	0.426	-0.017	-0.584

ML CoM velocity	0.283	0.188	0.296	-0.067	0.327	0.067	0.537
Sagittal ankle ROM	0.108	-0.002	0.462	0.459	0.130	0.027	-0.536

Appendix XVIII - Supplementary material of Study VII

Supplementary material

Table 1: Principal component model of tridimensional trunk, hip, knee and ankle range of motion (ROM), joint velocity range, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Sit-to-walk phase of TuG task. Kaiser-Meyer-Olkin value of 0.556 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S1)

Sit-to-walk phase

Principal component	1	2	3	4	5	6	7	8
Explained variance (%)	20.99	16.84	11.88	9.13	5.96	4.36	3.92	3.35
Sagittal knee ROM	**0.890**	0.02	-0.216	-0.107	-0.111	0.184	0.164	-0.167
Sagittal hip ROM	**0.825**	0.046	0.129	-0.175	0.128	0.079	0.136	0.150
Sagittal knee velocity range	**0.823**	-0.018	0.033	0.014	0.15	-0.051	0.237	-0.048
Vertical CoM displacement	0.780	0.074	0.374	-0.106	-0.262	0.164	-0.003	-0.122
Sagittal trunk ROM	0.676	0.121	-0.085	0.154	-0.029	-0.095	-0.353	0.310
Frontal knee ROM	0.671	0.052	-0.404	0.117	0.238	0.092	0.013	0.120
Transverse trunk velocity range	0.004	**0.865**	-0.043	-0.117	0.041	0.035	0.090	0.033
Frontal trunk joint velocity range	-0.020	**0.852**	-0.014	-0.132	0.173	0.118	0.073	0.045
Sagittal trunk joint velocity range	0.145	**0.848**	0.146	-0.009	-0.044	0.094	-0.217	-0.057
Transverse trunk ROM	0.014	0.720	0.052	0.03	-0.178	0.250	0.102	0.383
Transverse hip velocity range	0.354	0.509	0.063	0.01	0.287	0.024	0.327	0.347
Transverse hip ROM	0.436	0.476	-0.147	0.153	0.309	0.040	0.155	0.294
Vertical CoM velocity range	0.110	-0.045	**0.846**	0.048	-0.193	-0.118	0.120	-0.043
AP CoM displacement	-0.045	0.024	0.787	0.219	0.250	0.162	-0.241	-0.076
Sagittal hip velocity range	0.087	0.178	0.785	0.102	0.150	-0.081	0.189	0.389
AP CoM velocity range	-0.454	-0.029	0.639	0.336	0.208	-0.146	-0.01	-0.089
Sagittal ankle velocity range	-0.273	-0.05	0.553	0.513	0.046	-0.125	0.154	0.044
Frontal ankle ROM	0.150	0.221	0.504	0.403	-0.420	0.138	-0.065	0.014
Transverse ankle ROM	0.216	-0.091	-0.019	0.764	0.037	0.141	0.298	0.078
Sagittal ankle ROM	-0.241	-0.194	0.139	0.755	0.153	-0.039	-0.124	0.133
Transverse ankle velocity range	0.079	0.047	0.158	0.752	0.156	-0.283	0.232	0.025
Frontal ankle velocity range	-0.155	0.001	0.368	0.674	-0.117	-0.004	-0.053	-0.228
Transverse knee velocity range	0.129	0.012	0.091	0.153	**0.882**	-0.078	0.058	-0.083
Frontal Hip velocity range	-0.013	0.485	0.081	0.087	0.695	0.045	0.179	0.153
ML CoM displacement	0.159	0.044	-0.075	-0.149	-0.064	**0.859**	-0.005	0.151
ML CoM velocity range	0.076	0.394	-0.106	-0.006	0.078	0.78	-0.083	-0.176

Frontal hip ROM	0.056	0.267	0.189	0.115	-0.427	0.54	0.291	0.262
Frontal knee velocity range	0.193	0.02	0.031	0.245	0.191	-0.056	0.737	0.079
Transverse knee ROM	0.39	0.248	0.057	0.09	-0.104	0.092	0.435	-0.222
Frontal Trunk ROM	0.013	0.511	0.048	0.028	-0.069	0.121	-0.044	0.68

Table 2: Principal component model of tridimensional trunk, hip, knee and ankle range of motion (ROM), joint velocity range, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Walking forward phase of TuG task. Kaiser-Meyer-Olkin value of 0.635 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S2)

Walking forward phase

Principal component	1	2	3	4	5	6	7	8	9
Explained variance (%)	28.22	12.90	9.37	7.54	6.87	5.57	4.63	3.58	3.40
Sagittal knee velocity range	**0.874**	0.210	-0.004	0.144	0.19	-0.06	-0.03	0.032	-0.044
Sagittal hip ROM	**0.865**	0.037	0.025	0.144	0.11	-0.012	0.086	0.067	0.221
Vertical CoM velocity range	**0.800**	0.106	0.02	0.04	0.005	0.09	0.096	0.394	0.123
Sagittal Hip velocity range	0.777	0.307	0.036	0.267	0.132	0.04	0.194	-0.099	0.243
AP CoM velocity range	0.728	0.136	0.075	0.072	-0.114	0.034	0.038	0.141	0.015
Sagittal knee ROM	0.724	0.07	0.185	0.044	0.200	-0.002	-0.314	-0.027	-0.311
Vertical CoM displacement	0.648	-0.04	-0.024	-0.095	-0.207	-0.008	0.153	0.644	0.051
Transverse trunk ROM	0.549	0.258	0.072	0.424	0.208	-0.118	-0.009	-0.008	0.310
Frontal hip velocity range	0.485	-0.013	0.39	0.312	0.44	0.205	0.089	-0.197	-0.054
Sagittal ankle ROM	0.17	**0.865**	-0.1	-0.026	0.098	0.096	0.015	-0.116	-0.042
Transverse ankle velocity range	0.11	**0.85**	0.172	0.165	-0.038	-0.135	0.071	0.142	0.098
Transverse ankle ROM	0.057	**0.835**	0.019	0.151	0.157	-0.109	0.192	0.163	0.118
Sagittal ankle velocity range	0.442	0.755	0.047	0.075	0.052	0.106	0.104	-0.174	-0.058
Transverse hip velocity range	0.117	0.191	**0.884**	0.069	0.046	0.135	0.103	0.076	0.083
Transverse hip ROM	-0.04	-0.063	**0.86**	0.104	0.064	0.132	0.083	0.017	0.059
Transverse knee velocity range	0.163	0.047	**0.837**	0	-0.089	0.189	0.067	0.007	-0.035
Sagittal trunk velocity range	0.08	0.1	0.045	**0.907**	-0.044	0.15	-0.041	0.106	-0.172
Frontal trunk velocity range	0.117	0.032	0.107	**0.889**	0.147	0.01	-0.02	-0.02	-0.028
Transverse trunk velocity range	0.352	0.186	-0.008	0.788	-0.066	0.103	0.186	-0.014	0.019
ML CoM displacement	-0.071	0.057	-0.052	-0.054	**0.892**	0.127	0.17	0.015	-0.081
ML CoM velocity range	0.24	0.114	0.008	0.055	**0.847**	0.034	0.106	0.11	0.152
Frontal hip ROM	0.401	0.292	0.102	0.279	0.46	0.143	-0.084	-0.197	0.336
Frontal knee velocity range	0.073	0.045	0.257	0.196	0.223	**0.856**	-0.003	-0.107	-0.066
Frontal knee ROM	0.004	-0.039	0.434	0.18	-0.016	0.721	0.004	0.056	0.253
Transverse knee ROM	-0.063	-0.125	0.604	-0.109	0.038	0.637	-0.015	-0.014	0.098

Frontal ankle velocity range	0.163	0.195	0.137	-0.019	0.024	0.106	**0.868**	0.006	-0.062
Frontal ankle ROM	-0.036	0.111	0.136	0.103	0.315	-0.133	**0.82**	-0.097	-0.131
Sagittal trunk ROM	0.186	0.033	0.089	0.087	0.152	-0.063	-0.137	**0.897**	0.013
AP CoM displacement	-0.14	-0.059	-0.087	0.22	-0.035	-0.164	0.161	-0.032	-0.797
Frontal trunk ROM	0.373	0.091	0.268	0.097	0.398	-0.288	-0.077	0.126	0.431

Table 3: Principal component model of tridimensional trunk, hip, knee and ankle range of motion (ROM), joint velocity range, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Turn phase of TuG task. Kaiser-Meyer-Olkin value of 0.754 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S3)

Turn phase

Principal component	1	2	3	4	5	6	7
Explained variance (%)	35.41	15.93	10.52	6.58	5.21	4.70	3.46
Vertical CoM velocity range	**0.903**	0.033	-0.012	0.128	0.142	0	-0.055
Vertical CoM displacement	**0.889**	0.029	-0.082	0.062	-0.028	-0.123	0.108
AP CoM velocity range	**0.849**	-0.006	0.072	0.263	0.117	0.252	0.111
Sagittal knee velocity range	0.753	0.031	0.192	0.138	0.389	0.327	0.062
Sagittal knee ROM	0.715	0.044	0.303	0.11	0.269	0.315	0.017
Sagittal hip ROM	0.682	0.241	0.14	0.181	0.176	0.321	0.284
Sagittal hip velocity range	0.644	0.492	0.212	0.216	0.3	0.207	0.076
Frontal trunk velocity range	-0.06	**0.951**	-0.085	-0.03	0.101	-0.065	-0.035
Sagittal trunk velocity range	-0.096	**0.95**	0.026	-0.017	0.082	-0.022	-0.065
Frontal trunk ROM	0.162	**0.834**	-0.12	0.024	-0.117	0.161	0.266
Frontal hip velocity range	0.159	**0.801**	0.357	-0.03	0.208	0.066	-0.149
Sagittal trunk ROM	0.146	0.767	0.218	-0.04	-0.032	0.203	-0.09
Transverse trunk velocity range	-0.026	0.648	0.043	0.232	-0.31	-0.16	0.267
Frontal hip ROM	0.406	0.602	0.29	0.222	-0.006	0.187	0.25
Transverse knee velocity range	0.175	-0.002	**0.897**	-0.012	0.136	0.114	-0.009
Transverse knee ROM	-0.02	-0.07	**0.855**	0.012	0.053	-0.011	0.243
Frontal knee ROM	-0.036	0.172	**0.843**	0.168	0.097	-0.006	0.091
Transverse hip velocity range	0.225	0.261	0.754	0.027	-0.119	0.08	-0.342
Transverse ankle ROM	0.075	0.067	0.075	0.777	0.174	0.361	-0.046
Sagittal ankle ROM	0.474	-0.001	-0.058	0.756	-0.05	-0.043	0.268
Sagittal ankle velocity range	0.534	0.037	0.057	0.747	0.144	0.152	0.102
Transverse ankle velocity range	0.155	-0.032	0.342	0.62	0.484	0.314	-0.065
ML CoM displacement	0.188	0.006	0.032	0.126	**0.855**	0.165	0.202
ML CoM velocity range	0.531	0.012	0.049	0.135	0.734	0.164	0.064
Frontal knee velocity range	0.407	0.139	0.406	0.235	0.453	0.058	-0.051
Frontal ankle ROM	0.191	0.047	0.118	0.206	0.105	**0.846**	0.127

Frontal ankle velocity range	0.261	0.166	-0.057	0.245	0.293	0.774	-0.169
AP CoM displacement	0.36	0.22	0.119	0.068	0.198	-0.059	0.677
Transverse hip ROM	0.064	0.346	0.514	-0.128	-0.323	0.006	-0.557
Transverse trunk ROM	0.483	0.079	0.261	0.089	-0.069	0.305	0.486

Table 4: Principal component model of tridimensional trunk, hip, knee and ankle range of motion (ROM), joint velocity range, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Walking back phase of TuG task. Kaiser-Meyer-Olkin value of 0.653 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplmentary table S4)

Walking back phase

Principal component	1	2	3	4	5	6	7	8
Explained variance (%)	28.48	11.35	9.43	7.29	6.51	5.37	4.87	4.10
Sagittal hip ROM	**0.890**	0.009	-0.004	0.09	0.037	-0.01	0.066	-0.122
Sagittal knee velocity range	**0.843**	0.101	0.043	0.076	0.147	0.081	0.079	0.069
Sagittal hip velocity range	**0.842**	0.202	0.122	0.192	0.188	0.062	0.213	-0.156
Vertical CoM velocity range	**0.813**	0.221	-0.015	0.157	-0.18	0.075	0.187	0.163
Sagittal knee ROM	0.778	0.042	0.07	-0.065	0.05	0.093	-0.082	0.193
Transverse trunk ROM	0.686	0.184	0.296	-0.117	0.067	-0.14	0.088	0.162
Frontal hip ROM	0.636	0.319	0.016	0.12	0.359	-0.226	-0.048	-0.015
Vertical CoM displacement	0.596	0.07	-0.069	0.158	-0.332	0.176	0.162	0.395
Frontal trunk ROM	0.536	0.154	0.147	-0.012	0.036	-0.365	0.306	0.45
Transverse ankle velocity range	0.100	**0.801**	0.069	0.137	0.336	-0.03	0.094	-0.018
Transverse ankle ROM	0.054	0.772	0.157	-0.135	0.22	0.149	-0.082	0.211
Sagittal ankle ROM	0.234	0.76	0.03	0.051	-0.287	0.169	0.105	-0.143
Sagittal ankle velocity range	0.523	0.72	0.004	0.116	0.004	0.039	0.143	-0.08
Sagittal trunk velocity range	-0.057	0.05	**0.938**	-0.048	-0.045	0.152	-0.052	-0.016
Frontal trunk velocity range	0.033	0.037	**0.928**	0.039	-0.015	0.078	0.07	0.049
Transverse trunk velocity range	0.333	0.157	**0.813**	-0.105	0.089	0.117	0	0.123
Transverse hip velocity range	0.103	0.095	-0.064	**0.916**	-0.05	-0.083	0.08	-0.106
Transverse hip ROM	-0.012	-0.128	-0.01	**0.826**	0.046	0.043	-0.161	0.188
Transverse knee velocity range	0.14	0.242	-0.008	0.656	0.373	-0.052	0.314	-0.158
Frontal hip velocity range	0.545	0.092	-0.039	0.592	0.277	0.09	-0.086	0.099
Frontal knee ROM	0.063	0.114	-0.032	0.062	**0.812**	-0.095	0.151	-0.017
Transverse knee ROM	0.087	0.068	0.019	0.091	0.764	0.187	0.274	-0.068
Frontal knee velocity range	0.346	0.158	0.048	0.272	0.527	0.29	-0.087	0.204
AP CoM displacement	-0.242	-0.042	0.156	-0.154	-0.011	**0.874**	0.03	-0.059
Frontal ankle velocity range	0.239	0.323	0.316	0.068	0.134	0.651	-0.147	0.143
Frontal ankle ROM	0.211	0.442	0.223	0.048	0.225	0.586	-0.025	0.076

AP CoM velocity range	0.389	0.1	-0.088	0.175	-0.386	0.47	0.215	-0.046
ML CoM velocity range	0.167	0.042	0.033	0.082	0.138	0.045	**0.857**	-0.069
ML CoM displacement	0.098	0.059	-0.02	-0.087	0.149	-0.064	**0.831**	0.138
Sagittal trunk ROM	0.132	-0.03	0.101	0.022	-0.009	0.033	0.016	**0.885**

Table 5: Principal component model of tridimensional trunk, hip, knee and ankle range of motion (ROM), joint velocity range, and center of mass (CoM) displacement and velocity range in anteroposterior (AP), mediolateral (ML) and vertical directions during the Turn-to-sit phase of TuG task. Kaiser-Meyer-Olkin value of 0.594 and Bartlett's Test of Sphericity <0.05. Parameters with loadings >0.800 are in bold. (Supplementary table S5)

Turn-to-sit phase

Principal component	1	2	3	4	5	6	7	8	9
Explained variance (%)	20.96	14.22	9.16	8.02	7.04	5.60	4.20	3.90	3.71
AP CoM velocity range	**0.844**	0.166	0.027	0.199	-0.045	-0.229	-0.008	0.155	0.06
AP CoM displacement	0.784	0.345	0.074	0.064	0.041	-0.118	0.037	0.036	-0.086
Frontal Trunk ROM	0.703	-0.173	-0.039	-0.017	0.198	0.226	0.241	0.036	0.061
Frontal knee velocity range	0.604	-0.054	0.114	0.34	-0.079	0.338	-0.259	0.214	0.083
Sagittal hip velocity range	0.568	0.25	0.395	0.125	-0.113	-0.006	-0.033	0.26	0.409
Transverse trunk ROM	0.538	-0.371	0.204	0.26	0.14	-0.102	0.035	-0.115	0.447
Vertical CoM displacement	0.165	**0.890**	0.059	-0.077	0.186	-0.055	-0.068	-0.184	-0.002
Sagittal knee ROM	-0.248	0.755	0.128	-0.132	0.398	-0.005	-0.094	-0.175	-0.116
Transverse CoM velocity range	0.492	0.625	0.086	0.137	-0.026	-0.06	-0.054	0.032	0.362
Sagittal hip ROM	0.192	0.585	0.367	-0.329	0.13	-0.158	0.071	-0.107	-0.04
Frontal ankle ROM	0.414	0.5	-0.182	0.323	-0.305	0.091	0.368	0.188	-0.042
Transverse hip velocity range	0.006	0.237	**0.805**	-0.019	0.031	-0.02	-0.279	-0.009	0.23
Frontal hip velocity range	0.186	-0.175	0.694	0.129	-0.267	0.236	0.219	0.129	-0.139
Transverse hip ROM	0.063	0.133	0.675	-0.069	0.192	0.231	0.184	-0.299	-0.139
Sagittal knee velocity range	0.104	0.502	0.556	0.172	-0.097	-0.129	-0.039	0.051	-0.049
Transverse ankle velocity range	0.166	-0.22	0.143	**0.807**	-0.021	0.027	-0.047	0.161	0.081
Transverse ankle ROM	0.24	-0.056	-0.119	0.755	0.04	0.311	0.135	0.102	-0.081
Frontal ankle velocity range	0.166	0.401	0.196	0.588	-0.137	-0.04	0.063	0.312	-0.131
ML CoM displacement	-0.06	-0.004	-0.043	-0.046	0.788	0.212	0.029	0.079	-0.031
ML CoM velocity range	0.295	0.194	-0.018	-0.067	0.759	-0.15	0.053	0.128	-0.04
Sagittal trunk ROM	-0.046	0.382	-0.023	0.46	0.615	0.065	-0.101	-0.015	0.137
Transverse knee ROM	0.056	-0.037	-0.062	0.071	0.142	**0.892**	-0.031	-0.009	-0.075
Frontal knee ROM	-0.134	-0.087	0.275	0.13	0.005	0.65	0.092	0.083	0.14
Transverse knee velocity range	-0.017	-0.012	0.527	0.099	-0.114	0.549	-0.075	0.39	0.12
Frontal trunk velocity range	0.068	-0.214	0.105	-0.111	-0.012	0.01	**0.855**	0.056	0.061
Sagittal trunk velocity range	0.011	0.182	-0.1	0.239	0.057	-0.006	0.779	0.036	0.319
Sagittal ankle ROM	0.154	-0.169	-0.024	0.241	0.185	0.179	0.156	0.761	-0.058
Sagittal ankle velocity range	0.357	-0.057	0.078	0.413	0.175	0.04	0.061	0.731	0.045
Frontal hip ROM	0.438	0.146	0.274	0.266	0.113	0.055	0.185	-0.457	-0.018

Transverse trunk velocity range	**0.093**	**-0.035**	**-0.046**	**-0.097**	**-0.031**	**0.098**	**0.344**	**-0.014**	**0.796**