

The Effects of Inclined Treadmill Walking on Fall Risk
Prevention and Well-being in Older Adults: A Narrative
and Systematic Review

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Abstract

Falls among the elderly population are an ongoing concern. Falls lead to reduced independence, increased rates of mortality and disability, and diminished well-being and quality of life. Physical activity has been recognized as an effective approach to minimising fall risk in this population. However, the risk of falling itself can act as a deterrent to physical activity, exacerbating the problem. Limited knowledge exists regarding the effectiveness of inclined treadmill walking in older adults. This training modality has the potential to improve lower extremity strength and flexibility in older adults, as found in the promising outcomes in younger adults. This dissertation aimed to explore the impact of inclined walking on the well-being and quality of life of the elderly population. A comprehensive approach was used, comprising both a narrative review and a systematic review. The narrative review used nine articles, while the systematic review included six articles, with one article overlapping between the two. The narrative review used a broad literature search process focusing on walking, inclined walking, or the population of the elderly as the core search terms to build a comprehensive understanding of the topic. The systematic review followed PRISMA guidelines, utilizing a flow diagram for article screening and selection, and both reviews used a literature table to assist in synthesis purposes. Acute studies of inclined treadmill walking formed most of the literature over training studies due to the scarcity of the literature. The results indicated that flat-surface treadmill walking has a significant positive effect on well-being and quality of life among the elderly. Preliminary findings suggest that inclined walking also has a positive impact; however, the scarcity of literature necessitates further research on this topic. Positive results were noted through monitored nutrition, with an increased consumption of astaxanthin paired with inclined walking increasing postural control and strength measures. On the other hand, older adults were observed to have decreased muscle strength, impaired balance, and compensatory movements when inclined walking, and significantly increased fall risk at 70+ years. Older adults showed increased hip and decreased ankle joint work with decrease in ankle joint peak extensor moments and less peak power, and increased hip joint peak power compared to younger adults.

The findings highlighted a linear increase in fall risk with advancing age during inclined walking, emphasizing the need for heightened safety measures as individuals grow older, a limitation to this training within this population.

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Signed:

Chapter 1: Executive Summary

1.1 Dissertation Flow Chart

Figure 1. Flow Chart of Chapters within Dissertation

| |
|--|
| Chapter 1 Overview, Purpose, and Significance of the Research |
| Chapter 2 Introduction to the Topic of Fall Risk, Wellbeing and Quality of Life |
| Chapter 3 Methodology of the Narrative and Systematic Reviews |
| Chapter 4 Narrative Literature Review |
| Chapter 5 Systematic Literature Review |
| Chapter 6 Discussion and Conclusion |

1.2 Overview

According to the Accident Compensation Corporation (ACC) 2018 statistics, falling was the most common method of injury in New Zealand, with age considered the highest risk factor (ACC, 2019; HQSC, 2021). In 2018, one in three people >65 years old had a fall resulting in injury, with the rate rising to one in two at 80+ years (ACC, 2019). 193,954 people 65+ years of age suffered injuries from falling, with a total cost of \$267,275,845 (ACC, 2019). Ha et al., (2021) observed 539 outpatients aged 60+ and found frailty, fear of falling, activities of daily living (ADL) limitation, mobility impairment, and slow walking speed were significantly associated with falls, and 69.6% of those falls occurred within the home. Brauer et al. (1999), Cheng et al. (1998) Winter (2009) observed that reaching, sitting-to-standing, and walking require balance in the mediolateral plane and reduced balance in this plane can predict falls in

the older population (Hilliard et al., 2008; Maki et al., 1994). Additionally, a limited dorsiflexion range of motion (ROM) has been observed to increase fall risk in older adults (Bok et al., 2013; Menz et al., 2006; Menz et al., 2005; Menz & Lord, 2001). Afschrift et al. (2019) observed that older adults with deficient tibialis anterior (TA) activity are predisposed to utilizing stepping to control balance over ankle strategies in the mediolateral plane and this is important as the TA is the main muscle used for dorsiflexion.

In an Active New Zealand 2013/14 Survey, older adults (50+) were reported to have lower levels of participation in sports and active recreation (Haughey et al., 2015). Participation in daily activities has been observed to have a significant positive impact on health and contributes to a sense of satisfaction, accomplishment, well-being, and self-efficacy (Plaut et al., 2021), but fall risk hinders older people from participating in physical activity (Abey-Nesbit et al., 2021). This lack of physical activity exacerbates the individuals fall risk potential and thus reduces the quality of life (QOL) and overall well-being, which leads to reduced independence and requirement for medical aid and/or intervention (Plaut et al., 2021; Rejeski & Mihalko, 2001; Sherrington et al., 2020a). Walking has been identified as a healthy contributor to physical activity and fitness levels in older adults (Valenti et al., 2016), however, the effects of inclined walking on a treadmill are less understood. It is understood that in younger populations, inclined walking has a positive effect on flexibility and calf muscle strength over flat treadmill walking (Alexander & Schwameder, 2016; Franz & Kram, 2014; Haggerty et al., 2014). Additionally, treadmills with appropriate safety features (e.g., emergency stop and pull-cord, handrails, safety harness) create an environment where older individuals can walk with lesser fall risk and benefit from an increased level of physical activity potentiality (Pereira et al., 2020; University of Illinois at Chicago, 2014). The current New Zealand physical activity guidelines for older adults recommend “aerobic activity five days per week for at least 30 minutes if the activity is of moderate intensity; or for 15 minutes if it is of vigorous-intensity; or a mixture of moderate- and vigorous-intensity aerobic activity” (Ministry of Health, 2013). Recommendations also include “three sessions of flexibility and balance activities, and two sessions of muscle-strengthening activities per week” (Ministry of Health, 2013).

The National Institute for Health and Care Excellence (NICE) surveyed evidence on reducing harm from falls and found that evidence continues to support that balance and strength exercises, as well as other exercises with balance and/or strength components, reduce the fall risk potential in older adults (HQSC, 2020; NICE, 2019). Furthermore, supported, and supervised strength, balance, and walking training are effective population health prevention measures for falls and, for some, are the only means that older people need to reduce risk (HQSC, 2020; HQSC, 2021). Various interventions currently exist and are available for fall prevention, each with different components and levels of personalisation. Firstly, one type of intervention is the single-component intervention, which focuses on a single intervention or a combination of two interventions from the same category (Gillespie et al., 2012; Pillay et al., 2021). An example of a single-component intervention could be a program that incorporates walking and balance training with strength or resistance training (Sherrington et al., 2017). Another type of intervention is the multiple-component intervention, which includes multiple interventions from different categories. Multiple component interventions may include strategies or prescriptions such as exercise programs, medication management and/or environmental modifications (Lamb et al., 2005; Sherrington et al., 2017). Lastly, there are multifactorial interventions, which are tailored to the specific risk assessment of an individual. These interventions consider a variety of risk factors including visual and hearing impairments, chronic diseases, and/or medication use (Hopewell et al., 2018; Pillay et al., 2021). Overall, there are numerous intervention strategies available to prevent falls, and selecting the appropriate intervention depends on an individual's unique risk factors and abilities (Lamb et al., 2011; Pillay et al., 2021).

1.3 Purpose

The main purpose of this dissertation was to perform a systematic review on inclined treadmill walking and how several physical aspects in older adults are affected, such as dorsiflexion ROM and lower extremity musculature and biomechanics. By evaluating these affects, the research aims to identify promising exercise prescription strategies that could potentially help to improve

fall prevention intervention strategies for this demographic. In addition, this dissertation also includes a narrative review that explores how inclined treadmill walking could potentially benefit older individuals' physical and mental health and how that may affect well-being and QOL. Together, these analyses sought to contribute to a better understanding of the impacts of this training modality on older adults and offer suggestions for future research within this area of investigation and help to inform better evidence-based practice.

1.4 Significance of Study

Although research has been conducted using a cohort of older individuals and a treadmill training modality, the measure of balance regarding calf and hip dynamics is less reported and/or is not the primary focus of the research (Bok et al., 2013; Franz & Kram, 2014; Kwon & Shin, 2022; Menz et al., 2006; Menz et al., 2005; Menz & Lord, 2001; Yoon et al., 2013). Therefore, this dissertation will synthesise the currently available literature and help to create an understanding of whether inclined walking is of any benefit to the older population over flat surface walking. Furthermore, with current rates of risk of falls increasing and exercise adherence within older populations decreasing within New Zealand (Abey-Nesbit et al., 2021; ACC, 2019; Haughey et al., 2015; Ministry of Health, 2013), this research is significant because evidence shows that increased physical activity is predictive of lower fall potential (Abey-Nesbit et al., 2021; Plaut et al., 2021; Ministry of Health, 2013), and therefore findings that could improve physical activity are beneficial to society.

1.5 Research Questions and Objectives

The primary aim was to synthesise and analyse research on inclined treadmill walking in the older population and how it could affect fall risk potential in older adults. The hypothesis was that walking on an incline could cause an increase in the dorsiflexion ROM, thus eliciting an improvement in postural control and reducing fall risk potential. A secondary aim was to synthesise and analyse research on inclined treadmill walking in the older population and how it could affect well-being. The hypothesis was that walking at an incline could have positive

effects on calf and hip flexor strength, size, and/or elasticity, thus increasing fundamental movement capacity in older individuals and contributing to improved QOL and well-being.

The main objective of this dissertation was to review if walking on a treadmill with an inclined track had any effect on postural stability and well-being in people over the age of 50 years where the findings could be used to improve fall prevention, adherence to exercise and/or recreational activities, and well-being through improved ADL ability and QOL. This review endeavoured to reach a better understanding of treadmill walking as a training modality and how it could be related to the complex issue of falls within the older population. However, inclined walking training studies were scarce, and so acute studies were required to be included. This was done using a combination of methods: a narrative review to examine qualitative and quantitative examinations of falls and their physical and mental effects, and a systematic review to examine quantitative research to examine how dorsiflexion and hip flexor ROM biomechanics and strength are affected by inclined walking.

1.6 Summary of the Methodology

The methodology that will be used within this research is a broad narrative review and a systematic review. The narrative review will be used to build a foundation for the topic using qualitative and quantitative research examinations, while the systematic review will be used to focus on the biomechanics of the lower extremities in response to the training modality.

1.7 Dissertation Structure

This dissertation consists of six chapters which are organised as follows:

- Chapter one outlines the significance and the purpose of the research and the primary and secondary research questions.
- Chapter two introduces and provides a general background to the research topic.

- Chapter three displays the methods used for the narrative and systematic reviews including literature tables and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Page et al., 2021).
- Chapter four outlines, introduces, and displays the findings of the narrative review.
- Chapter five outlines, introduces, and displays the findings of the systematic review.
- Chapter six covers the discussion and conclusion sections where the findings of both the narrative and systematic reviews will be discussed and limitations, recommendations, and areas of future research are identified.

Chapter 2: Introduction

Falls among older adults are a major public health concern, as they often result in serious injuries, reduced independence, and increased healthcare costs. Across New Zealand and Australia, falls among older adults in the 65+ age group account for 40% of injury-related deaths and 1% of total deaths (Hopewell et al., 2018; Sherrington et al., 2020a). With the ageing of the population, the incidence of falls increases in a linear trend (Ministry of Health, 2013; Sherrington et al., 2020b), making fall prevention an important priority for policymakers within healthcare, as well as healthcare providers.

Regular physical activity, including walking, has been shown to reduce fall risk and improve well-being in older adults (Abey-Nesbit et al., 2021; Plaut et al., 2021; Ministry of Health, 2013). Walking is a simple, low-impact exercise form that can be easily integrated into daily routines; however, traditional walking programs may not provide enough challenge or variety to maintain interest and/or adherence, particularly for those with mobility limitations. Inclined treadmill walking is a promising alternative that provides additional challenges to the lower body and may have unique benefits for fall prevention and well-being due to the increased stress placed across the joints and musculature of the lower extremities.

Previous research has suggested that inclined walking on a treadmill provides additional benefits to traditional level walking, such as increased lower body strength, cardiovascular fitness, and improved balance (Franz & Kram, 2014; Haggerty et al., 2014; Pereira et al., 2020; Alexander & Schwameder, 2016). However, most of this literature is on young adult subjects with few studies having examined the effects of inclined treadmill walking in older adults and how it affects fall risk prevention and well-being.

Therefore, this dissertation aims to review inclined treadmill walking and how it could affect fall risk prevention and well-being in older adults. Specifically, this study reviewed the current literature that includes inclined treadmill walking as either an acute or training method with a measured variable of fall risk, balance, gait, muscle strength, muscle flexibility, joint mobility and/or QOL in older adults. Acute studies were included due to a major gap in the literature

with training studies. The study will also explore the feasibility and acceptability of inclined treadmill walking as a training modality for this age group, as well as discuss the perceptions of benefits and challenges this type of training could pose specifically to the age group.

By understanding the effect of inclined treadmill walking on fall risk prevention and well-being in older adults, exercise programs could be better designed and administered in a manner that promotes healthy ageing with a reduction in the risk of falls among this increasingly vulnerable population.

2.1 Fall Potential

Falls can lead to serious injuries, loss of independence, and reduced QOL. As a result, identifying and addressing factors that contribute to fall risk is critical for promoting healthy ageing.

Fall potential is a term used to describe an individual's likelihood of falling. This fall potential is influenced by a variety of factors, including medication use, chronic health conditions, gait, cognitive function, balance, muscle strength, and environmental factors such as poor lighting and uneven surfaces (Menz et al., 2006; Rejeski & Mihalko, 2001; Sherrington et al., 2020a). Changes in these factors as individuals age can increase fall potential, as age-related declines in muscle strength and balance control can lead to an increased risk of falling (Menz & Lord, 2001; Plaut et al., 2021; Rejeski & Mihalko, 2001). Additionally, changes in cognitive function can impact an individual's ability to maintain balance and increase fall risk (Rejeski & Mihalko, 2001). Understanding the relationship between these factors and fall potential is essential for developing effective fall prevention strategies. In the context of inclined treadmill walking, fall potential is of particular interest as the incline changes the demands on an individual's balance, gait, and lower body strength; however, it is unclear if these demands generate a positive effect on older adults.

Fall potential can be assessed using a variety of methods, including standardized assessments such as the Timed Up and Go test, the Berg Balance Scale, and the Four-Square Step Test

(Kwee-Meier et al., 2018; Pereira et al., 2020). These assessments measure an individual's balance, gait, and lower body strength, which are important contributors to fall potential. Inclined treadmill walking may increase fall potential due to the added demands of these factors. Walking uphill on a treadmill incurs a greater lower body strength and balance control demand than walking on a level surface. Additionally, walking on a treadmill may require greater cognitive resources to maintain balance and gait control, which could also impact fall potential. Understanding the relationship between an inclined treadmill walking modality and fall potential in older adults is essential to develop improved and effective exercise programs.

2.2 Overview of Global Fall Potential Rates

The second leading cause of unintentional or accidental injury deaths worldwide is falling, according to the World Health Organization (WHO), with the first being road traffic fatalities (WHO, 2021). An estimated 684,000 individuals die from falls globally each year, with 80% of these deaths occurring in middle- and low-income countries (WHO, 2021).

The prevalence of fall potential varies across different regions and countries. Salari et al. (2022) observed a fall prevalence of 26.5% with a total sample size of 36,740,590, though interestingly, Oceania had the highest prevalence at 34.4%, followed by America at 27.9%, while the lowest rates were reported in Africa and Europe (Salari et al., 2022). Risk factors for falls are also influenced by geographical and cultural factors. WHO (2021) and Salari et al. (2022) identified that older adults in low- and middle-income countries may have a higher risk of falls due to inadequate healthcare and poor living conditions, which contrasts with reports of Africa having one of the lowest rates (Salari et al., 2022), however this could be because only two articles from Africa were sourced. Disparities in fall potential rates exist within individual countries, as older adults that live in rural areas may have a higher risk of falls due to limited access to community resources and/or ease of access to healthcare providers. Additionally, socioeconomic factors such as income and education level are observed to impact fall potential in older adults (Kim et al., 2020; WHO, 2021).

2.3 Current Trends of Fall Potential in New Zealand

Recent studies have highlighted the high prevalence of fall risk factors in older adults in New Zealand. Bloomfield et al. (2020) saw that half of community-dwelling people aged 80 years and over experienced at least one fall per year from risk factors such as poor balance and muscle weakness. Furthermore, the relationship between sedentary behaviour and fall risk in older adults has been observed showing that sedentary behaviour is associated with an increased risk of falls, while physical activity was associated with decreased fall risk potential (Hopewell et al., 2018; Pereira et al., 2020; Sherrington et al., 2020a; University of Illinois at Chicago, 2014).

In terms of fall prevention strategies, the New Zealand Ministry of Health recommends a multifactorial approach that addresses multiple fall risk factors simultaneously (Ministry of Health, 2013). This approach includes vision assessments, exercise programs to improve balance and strength, medication reviews, and modifications to an individual's living environment (Lamb et al., 2011; Pillay et al., 2021; Ministry of Health, 2013).

Overall, fall prevention remains a significant challenge in New Zealand, where the ageing population and high prevalence of fall risk factors underscore the need for effective prevention strategies. Understanding the current trends of fall potential in older adults in New Zealand is critical for developing and implementing effective fall prevention interventions.

2.4 Well-being and Quality-of-life

Well-being is a multidimensional construct that contains various aspects of an individual's overall QOL and satisfaction with their psychological, physical, and social functioning. Wilcock (2006) suggests that well-being consists of three interconnected aspects: mental, physical, and social well-being, which aligns with an ecological model of well-being proposed by Ryan and Deci (2001). This model emphasizes the importance of basic psychological needs, such as competence, autonomy, and relatedness, in promoting well-being. Physical well-being involves utilizing one's physical capacities, while mental well-being entails emotional experiences, intellectual challenges, and relaxation. Social well-being is achieved through maintaining and developing satisfying personal and social relationships (Wilcock, 2006). Well-being in the

context of older adults has factors such as social support, engagement in meaningful activities, and a sense of purpose, which align with the ecological model proposed by Ryan and Deci (2001). These are essential for promoting healthy ageing and enhancing the overall QOL in this population (Dehi et al., 2014; Plaut et al., 2021; Pereira et al., 2021; Wilcock, 2006).

The World Health Organization Quality of Life (WHOQOL) Group defines QOL as an individual's subjective perceptions of their position in life, considering their expectations, goals, standards, and concerns within the environmental, social, and cultural context within their daily life (Harper et al., 1998). This definition recognizes that QOL is a subjective assessment influenced by environmental, social, and cultural factors (Harper et al., 1998).

Well-being and QOL assessment are critical considerations when addressing life satisfaction and the overall health of older adults. Falls among this population can have a large negative impact on their well-being, leading to increased healthcare needs, decreased independence, and a decline in overall QOL (Hopewell et al., 2018; Sherrington et al., 2020a).

ADL ability plays a significant role in maintaining well-being and QOL, as the basic tasks necessary for self-care and independence are categorised within ADL. An older adult's ability to perform ADLs, such as eating, bathing, and dressing directly impacts their overall well-being and satisfaction with life (Gitlin et al., 2001). Addressing fall risk through training interventions can potentially improve well-being and enhance the overall QOL for older adults through the improvement of general ADL ability (Abey-Nesbit et al., 2021; Plaut et al., 2021; Kuhman et al., 2018).

Psychological factors contribute to well-being and QOL in older adults. Cognitive function, mental health, and emotional well-being are essential components that influence an individual's overall sense of fulfilment and/or life satisfaction (Abey-Nesbit et al., 2021; Sherrington et al., 2020b). Promoting cognitive vitality and maintaining emotional well-being and positive mental health are all important aspects that each enhance the well-being and QOL of older adults (Meeks et al., 2012). Regular physical activity has been observed to have numerous benefits for well-being and QOL in older adults. Exercise has been linked to reduced risk of chronic

diseases, improved mental health, increased social engagement, and enhanced cognitive function (Abey-Nesbit et al., 2021; Plaut et al., 2021; Meeks et al., 2012; Ministry of Health, 2013). Maintaining independence, improving life satisfaction, and promoting a sense of purpose in older adults all have the potential to occur through engaging in physical activity (Hopewell et al., 2018; Pereira et al., 2020; Plaut et al., 2021). In addition to physical benefits, physical activity has a potential influence on psychological well-being. Exercise has been linked to reduced symptoms of anxiety and depression, improved self-esteem, and enhanced cognitive function in older adults (Abey-Nesbit et al., 2021; Ministry of Health, 2013; Plaut et al., 2021). The sense of achievement that can occur during sessions of physical activity could further contribute to improved mental well-being and overall QOL in older adults.

By considering and addressing the broader aspects of well-being and QOL, healthcare providers and policymakers can make a significant impact on the lives of older adults. Implementing interventions that focus on ADLs, mental health, emotional well-being, and cognitive function can enhance their overall satisfaction, sense of purpose, and QOL.

The American College of Sports Medicine (ACSM) recommends that older adults engage in aerobic exercise for at least 30 minutes per day, five days per week, at a moderate intensity, similar to recommendations of the New Zealand Ministry of Health (American College of Sports Medicine et al., 2009; Ministry of Health, 2013).

Overall, promoting well-being and enhancing the QOL in older adults is a complex task that includes various aspects, such as fall prevention, physical activity, and improvement of mental health and cognitive function.

2.5 Inclined Treadmill Walking Training

Inclined treadmill walking training involves walking on a treadmill that is set at an incline, which increases the demands on the muscles, ligaments, and joints within the lower extremities, balance control, and cognitive processing. Inclined treadmill walking training varies depending on the fitness level and goals of the individual. Typically, inclined walking programs involve

gradually increasing the treadmill incline over time, while also varying the speed and duration of the exercise. Common inclines for inclined walking training observed in the current literature is between 2 – 8°, or gradients between 3.5% – 14% (Franz & Kram, 2013; Franz & Kram, 2014; Kwee-Meier et al., 2018; Liu et al., 2018; Morrison et al., 2016; Waanders et al., 2019; Waanders et al., 2020; Walsh et al., 2018).

Chapter 3: Methodology

3.1 Overview

This chapter describes the research methods undertaken for the narrative and systematic literature reviews to investigate the research questions. This chapter is divided into two sections where each review is described in its own section. The narrative literature review in the first section covers how the literature search was performed and details the broad level of literature used to investigate inclined walking and how it could affect well-being and/or fall potential in the elderly population. The second section explains the systematic literature review which contains a PRISMA flow diagram (Page et al., 2021); the search terms used to obtain the literature, and the inclusion and exclusion criteria used to ensure the literature is fit to answer the research question of the effect of inclined walking on dorsiflexion ROM in the elderly population.

3.2 Narrative Literature Review

A narrative literature review was chosen to synthesize the available literature on the effect of inclined treadmill walking on well-being and fall prevention within the elderly population. This review basis was selected because unlike systematic reviews, which follow a rigorous and strict methodology, narrative reviews are flexible and more subjective which allows for a broader scope of investigation and is ideal to answer the research question.

To support this dissertation, this narrative review serves several purposes. Firstly, it helps to establish the context and background of the topic and/or research question that is being investigated (Hart, 2018). By reviewing and discussing relevant literature, the researcher then demonstrates an understanding of the existing knowledge and identifies gaps or areas, contradictions, and commonalities that require further exploration through the synthesis of the findings (Hart, 2018). This synthesis helps build an argument for the significance and novelty of

the proposed research, highlighting the potential contribution to the field as well as providing insight into future recommendations.

Secondly, a narrative review contributes to the development of the theoretical framework for the dissertation. It helps identify and select models, theories, and/or concepts that could be relevant to the research question and provides a foundation for subsequent research and analysis (Hart, 2018; Ridley, 2012).

Lastly, with the critical analysis of the literature, a narrative review can identify areas where either existing knowledge is limited, or further research is needed. This identification of research gaps informs the research objectives and research questions of the dissertation (Hart, 2018).

3.2.1 Search Strategy

The literature search was conducted in the electronic databases Google Scholar, PubMed, Scopus, and the EBSCO Health Databases SportDiscus, MEDLINE, and CINAHL Complete. The strategy that was used for the literature search was an assortment of words and/or a collection of words that broadly covered the topic while maintaining at least one core search term. The core search terms were identified as the training modality of walking, the training modality of inclined walking, or the population of the elderly. Examples of the broader search terms covered were phrases such as: “fall potential”, “fall prevention”, “well-being”, “quality-of-life”, and “uphill walking.” A combination of these search terms was used to identify relevant articles.

3.2.2 Inclusion/Exclusion Criteria

- Studies that evaluated the effects of walking, inclined walking, and/or sloped walking.
- Studies that used a cohort of the elderly population.
- Studies that observed the effects of walking at flat and/or declined gradient angles to be compared with inclined walking methods.
- Studies that use acute or training methods

- Studies that use ROM, flexibility, strength, or mobility in the knee, ankle, and/or hip joints as dependent variables.

3.2.3 Data Extraction

Relevant data from the selected articles were extracted by the researcher and presented in relevant literature tables, which included information such as researcher(s) and year of publication, participants, observed variables, details of the intervention, and the observed findings.

3.2.4 Data Synthesis

The data collected from the chosen studies were synthesised by the researcher by comparing the data presented within the literature table(s), enabling a concise presentation of the findings. This review aimed to provide a comprehensive analysis of how the physical activity of inclined walking impacted the musculature and flexibility of the lower extremities in the elderly population. Additionally, this review explored the effects on well-being and the potential risk of falls, ensuring a better understanding of the exercise modality.

3.3 Systematic Literature Review

A systematic review is a comprehensive and rigorous synthesis of existing literature on a specific research question or topic (Higgins et al., 2022). This type of review follows a transparent and defined methodology to identify, screen and select, critically appraise, and synthesize relevant research. This type of review is used to identify trends, gaps, and/or patterns in the literature, which suggests areas for future research and highlights the strengths and weaknesses of the existing evidence (Higgins et al., 2022). A systematic review was selected to evaluate the effect of inclined walking on lower extremity musculature and flexibility within the ankle joint in the elderly population. The review was conducted according to the PRISMA guidelines (Page et al., 2021).

To support this dissertation, this systematic review serves several purposes. Firstly, it helps to clarify the objective and/or research question of the dissertation. This occurs through a

systematic approach to defining the boundaries and scope of the review, ensuring that the research question is answerable as well as well-defined through the currently available literature (Higgins et al., 2022; Petticrew & Roberts, 2006).

Secondly, a systematic review involves a comprehensive and systematic search of databases, journals, and other sources to identify all relevant studies related to the research question utilizing the same search terms across all databases. Inclusion and exclusion criteria are established to ensure the selection of studies that meet the specific standards of both relevance and/or quality (Higgins et al., 2022).

Furthermore, a systematic review critically appraises the validity and the quality of included studies using predefined criteria such as within the PRISMA guidelines (Higgins et al., 2022; Page et al., 2021). This appraisal helps assess the limitations, strengths, and weaknesses of the available evidence, ensuring that only relevant studies that are of quality are included within the synthesis (Higgins et al., 2022; Petticrew & Roberts, 2006).

Lastly, systematic reviews involve extracting relevant data from the included studies and synthesizing the findings using appropriate statistical methods. The systematic review within this dissertation used a narrative synthesis, which provided an interpretation and summary of the findings (Higgins et al., 2022).

3.3.1 Search Strategy

The systematic literature review search was conducted in the electronic databases Scopus and the EBSCO Health Databases SportDiscus, MEDLINE, and CINAHL Complete.

The search terms used were:

- Dorsiflexion OR "Dorsiflexion ROM" OR "Dorsiflexion range*" OR "Ankle ROM" OR "Ankle Joint" OR Ankle
- AND "Older adult*" OR "Older People*" OR elder* OR senior* OR geriatric*
- AND treadmill OR walkway
- AND incline OR inclined OR sloped OR gradient OR Uphill

It is important to note that well-being and QOL were not within the search terms as the systematic portion of this paper focused on the effect of inclined walking on lower extremity biomechanics in older adults.

3.3.2 Inclusion/Exclusion Criteria

The inclusion and exclusion criteria for the articles were:

- A method of walking at an incline was used.
- Studies that had a minimum age of 50 years for participants.
- ROM, strength, flexibility, or mobility of the ankle joint is one of the dependent variables.
- Subjects were able-bodied and did not use prosthetics, robotics, or devices to assist with walking.
- Studies use acute or training methods

3.3.3 Data Extraction

The researcher screened the titles and abstracts of the articles retrieved from the search based on the inclusion and exclusion criteria. The full text of potentially eligible articles was then retrieved and assessed for eligibility. Any discrepancies between the researcher's review and the researcher's supervisors were resolved through discussion or consultation between the parties.

3.3.4 Quality Assessment

The studies were assessed for bias in selection, performance, detection, attrition, reporting, and other potential sources of bias. Any discrepancies between the researcher's review and the researcher's supervisors were resolved through discussion or consultation between the parties.

3.3.5 Data Analysis

The data extracted from the selected studies were analysed and synthesized using a narrative synthesis to summarize the findings of the studies. A narrative synthesis is an approach to reviewing and synthesizing existing literature that focuses on interpretation and qualitative analysis. It involves summarizing and integrating findings from multiple studies to generate a

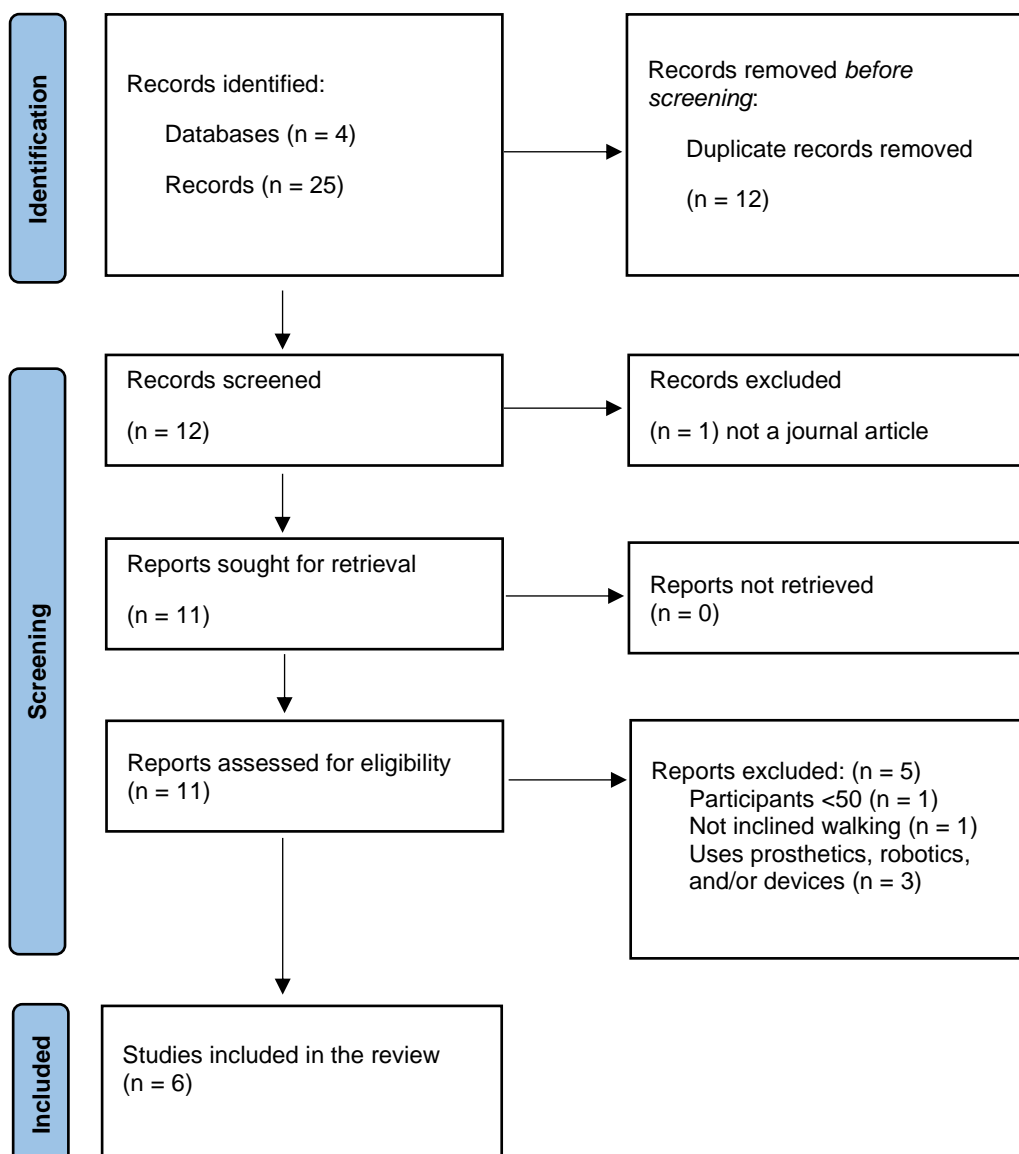
coherent and narrative account of the research question that is being investigated (Popay et al., 2006). This form of analysis involves critical and interpretive analysis of literature. It explores patterns, divergences, and relationships across studies (Dixon-Woods et al., 2007).

Lastly, narrative synthesis aims to integrate the findings of multiple studies to generate a cohesive narrative (Dixon-Woods et al., 2007). It combines evidence from various sources to provide a detailed overview of the research topic.

3.3.6 PRISMA Flow Diagram

The process of sourcing, screening, and selecting articles for the systematic literature review is detailed in the PRISMA diagram below (Figure 2).

Figure 2. Systematic Literature Review PRISMA Flow Diagram



3.3.7 Conclusion

This systematic review was used to provide an evidence-based evaluation of the effect of inclined treadmill walking on lower extremity biomechanics with a focus on the ankle in the elderly population.

Chapter 4: Narrative Review

4.1 Overview

This chapter contains a narrative literature review that centres around the subject of inclined walking and its impact on well-being and fall prevention among the elderly population. Through comprehensive exploration, this review seeks to synthesise the reported effects on cognitive and/or physical variables observed in the population who have undergone training in this specific modality. This review is broad and will scrutinize the spectrum of various effects that have been documented within this population through both qualitative and quantitative research. This will help in understanding any potential interplay between inclined walking and the multifaceted domains of well-being and fall prevention. Exploring further, the findings will be compared to relevant literature which will be used to highlight any similarities, distinctive patterns, and/or contrasts and better help identify any positive and/or negatives to well-being and/or fall prevention that emerge from this. Consequently, this review endeavours to uncover a narrative that intertwines the modality of inclined walking with the many aspects of well-being and/or fall prevention and contributes valuable insight and enriches the existing knowledge of physical activity recommendations within the elderly population.

4.2 Introduction

Extensive research has consistently observed the positive impact of physical activity on overall well-being across all age groups (Haggerty et al., 2014; Plaut et al., 2021). It is also well-documented that physical activity has been found to enhance body fitness, which in terms of increased postural control results in a reduced likelihood of falls (Hilliard et al., 2008; Plaut et al., 2021). However, it is well documented that the ageing process entails a gradual decline in muscular strength, flexibility, and mobility, accompanied by decreased elasticity in muscle tendons and surrounding tissues, and increased joint stiffness (Abey-Nesbit et al., 2021; Alexander & Schwameder, 2016). This decline in body fitness and control within the elderly

population has been correlated with an elevated risk of falls, coinciding with a noticeable decline in overall well-being (Ha et al., 2021; Plaut et al., 2021). Notably, an important aspect to consider in this review is the potential for physical activity, where due to diminished fitness levels, there is an increased risk of falls (Abey-Nesbit et al., 2021). Consequently, there is a tendency among older individuals to limit, minimize, or even avoid physical activity altogether, fearing the potential for injury-inducing falls (Abey-Nesbit et al., 2021; Rejeski & Mihalko, 2001), thereby exacerbating both issues in a negative cycle.

Walking has emerged as a widely recommended physical activity modality among the elderly population. It is deemed relatively safe, with the primary danger stemming from tripping hazards, and it is characterized by its low-impact nature and ease of integration into daily routines. Research has indicated that standard flat-surface walking can enhance well-being among the elderly (Franz & Kram, 2014; Alexander & Schwameder, 2016; Valenti et al., 2016). However, contrasting research suggests that, beyond a certain point, walking alone may fail to sufficiently challenge the lower extremities, necessitating an increase in speed and/or incline (Franz & Kram, 2014; Haggerty et al., 2014). Currently, available research suggests that walking on an inclined gradient, while maintaining a steady pace, intensifies the demands placed on the lower extremities and promotes the development of muscle strength and flexibility. It is worth noting, however, that this research primarily focuses on younger adults (Haggerty et al., 2014; Pereira et al., 2020; Alexander & Schwameder, 2016), with limited investigations conducted within elderly cohorts. Furthermore, it is important to acknowledge that inclined walking is considerably safer on a treadmill, equipped with safety devices and allows individuals to easily abort training in case of emergencies, compared to outdoor environments, for the general elderly population.

The primary objective of this review is to synthesize existing literature that investigates various forms of inclined walking interventions implemented among elderly cohorts, with a particular emphasis on discerning the impact of inclined walking on both well-being and fall prevention within this population. A comparative analysis will be undertaken to explore the distinctions between treadmill-based and outdoor walking approaches, as well as comparisons between

gym-based and community-based interventions, technological considerations, and pertinent physical variables.

4.3 Literature Search

It was made apparent during the literature search process that literature on this topic is scarce and needs further exploration. Because of the scarcity, articles that used various walking methods were included to compare with the found studies using an inclined walking modality. Furthermore, major gaps in the literature were discovered regarding training studies, and so acute studies were also included within the review.

4.4 Literature Tables

Because the articles found for this review used acute and training methods, multiple literature tables were warranted to differentiate between these studies. All articles included in the narrative literature review are within the below tables (Table 1, Table 2).

Table 1. Narrative Literature Review Table – Acute Studies

| Study | Participants | Variables | Intervention | Results |
|---------------------|--|---|---|---|
| Kuhman et al., 2018 | 32 older adults (22 female, age: 74.7 ± 4.4 years) males not specified compared to 10 young adults (7 female, age: 20.3 ± 1.5 years) males not specified | Short-Form Health Survey Physical Component (SF-36 PC), ratios of hip extensor to ankle plantar flexor peak torques, angular impulses, peak positive powers, and positive work through 3D gait analysis | 1 x testing session at self-selected and controlled walking speeds for level (1.30 m/s) and incline (1.20 m/s) gaits. No control group was used. | SF-36 PC scores = 5.4 lower than younger adults (53.7 ± 6.2 vs 59.1 ± 1.7, $p \leq .01$) Relative hip % work: 41.3 flat surface / 46.1 inclined Relative ankle % work: 41.9 flat surface / 34.4 inclined Stride length (m): 1.38 flat surface / 1.33 inclined while younger adults saw no change |
| Franz & Kram, 2014 | 10 older adults (6 female, 4 male) age: 72 ± 5 years compared to 8 young adults (4 female, 4 male) age: 27 ± 5 years | Sagittal plane ankle, knee, and hip joint kinetics compared to younger adults | 4 x 2min sessions on a treadmill (speed: 1.25m/s at increasing gradients per session (0, 3, 6, 9 / 5.2%, 10.5%, 15.7%)). No control group was used. | Young adults were observed to increase peak ankle extensor moments during uphill vs. level walking ($p = 0.003$) Older adults' ankle joint produced 25 ± 10% smaller peak extensor moments ($p = 0.001$) and 18 ± 16% less power ($p = 0.014$) than younger adults Older adults produced 119 ± 86% more peak power ($p = 0.013$) in the hip than younger adults preceding the off phase of inclined walking |

| | | | | |
|-------------------------|---|--|--|---|
| Kwee-Meier et al., 2018 | 26 older adults (13 female, 13 male) age: 66.19 ± 0.88 . compared to 26 young adults (13 female, 13 male) age: 24.31 ± 0.50 | EMG signals of the gluteus maximus, biceps femoris, rectus femoris, vastus medialis, gastrocnemius medialis and the soleus muscles | 4 x 2min sessions on a treadmill (speed: 2.75kmph at increasing gradients (2 flat, 1 at 7° incline and 1 at 14° incline). No control group was used. | walking uphill at 14° had a high RPE strain level for elderly people ($p \leq .001$) gender had a significant main effect on the gluteus maximus, vastus medialis, gastrocnemius medialis and soleus activity (stated but not explored) The elderly showed a significant increase and long activation of biceps femoris during only 14° inclined walking ($p \leq .001$) and a significant increase in all other muscles measured over both incline levels compared to younger adults |
| Morrison et al., 2016 | 75 healthy adults, aged: 30-79 years of age | Physiological Profile Assessment (fall risk assessment), simple reaction time, leg strength, walking ability and standing balance | 3 x 5-minute sessions (speed: faster than preferred) on a treadmill where the gradient was incrementally increased each minute from 2° to 8°. No control group was used. | Older adults exhibited increased postural sway via path length: 60–69 yrs; 10.2 ± 0.7 to 12.1 ± 0.7 cm 70–79 yrs; 12.8 ± 1.1 to 15.1 ± 0.8 cm, slower reaction speed: 70–79 yrs; 256 ± 6 to 287 ± 8 ms, lower limb strength: 60–69 yrs; 36 ± 2 to 31 ± 1 kg, 70–79 yrs; 32.3 ± 2 to 27 ± 1 kg. 70-79 years group had a significant falls risk increase: (pre; 0.51 ± 0.17 : post; 1.01 ± 0.18) |
| Walsh et al., 2018 | 16 older adults (6 female, 10 male), aged: 64 ± 5 years | Postural Control | 3 x 30min sessions (each broken up into 3x 10min blocks of walking then testing) on a treadmill on a flat surface and a gradient of 5.25%. No control group was used. | Significant increases following walking: Postural sway elliptical area: PRE: 1.38 ± 0.22 cm ² POST: 2.35 ± 0.50 cm ² , $p = .01$, Medio-lateral: PRE: 1.33 ± 0.03 , POST: 1.40 ± 0.03 , $p = .01$, Anterior-posterior detrended fluctuation: PRE: 1.43 ± 0.02 , POST: 1.46 ± 0.02 , $p = .04$ Medio-lateral decreased between post and 15-min rest: POST: 1.40 ± 0.03 , REST: 1.36 ± 0.03 , $p = .03$, Forward limits of stability decreased between interval 2 and rest: |

| | | | | |
|-------------------|--|--|---|--|
| | | | | Interval 2: $28.1 \pm 1.6\%$, REST: $25.6 \pm 1.6\%$, $p = .01$, and left limits of stability increased from pre-exercise to rest: PRE: $27.7 \pm 1.2\%$, REST: $29.4 \pm 1.1\%$, $p = .01$ |
| Hill et al., 2020 | 19 community-dwelling older adults (10 female, 9 male), aged: 70+, Group 1 (n = 4) = declined walking compared to Group 2 (n = 5) = flat surface walking | Postural sway, muscle torque and power, physical function and mobility | 1 x 30min session at a self-selected walking speed at a flat surface or a -10% gradient (decline). Tests were taken 1min, 15min, 30min, 24h and 48hrs after intervention. No control group was used. | Declined walking resulted in: postural sway: +66 to 256%, Timed up and go: +29%, The 60s sit-to-stand test: +29%, five times sit to stand test: -25%, concentric power: -33% and no change after 1-30mins Muscle torque immediately decreased at 1min and did not recover after 48hrs Flat surface walking incurred increased postural sway, slower timed up and go, fewer sit-to-stand cycles, and decreased muscle torque and power, but returned to baseline after 30min rest time |

EMG = electromyography, m = metres, m/s = metres per second, min = minutes, n = population chosen for study, p = significance, pre = before activity, post = immediately post activity, rest = 15 minutes after post activity, RPE = rating of perceived exertion

Table 2. Narrative Literature Review Table – Training Studies

| Study | Participants | Variables | Intervention | Results |
|-------------------|--|--|--|---|
| Dehi et al., 2014 | 66 female older adults, aged: 65-75 years Control group (n = 33) Experimental group (n = 33) | Quality-of-life questionnaire of the elderly | 3 x 30min sessions per week for 6 weeks on a treadmill (intensity: 2.5m; speed: 5kmph). A control group was used. | Pre: Physical Activity: 60.8 Self-Care: 85.56 Cognitive: 60.2 Life Satisfaction: 84.63 Post: Physical Activity: 68 (P=0.004) Self-Care: 85.56 (P=0.007) Cognitive: 60.2 (P=0.004) Life Satisfaction: 84.63 (P=0.001) |

| | | | | T-test (all) = P= \leq 0.001 |
|----------------------|--|---|--|--|
| Pereira et al., 2021 | 37 institutionalized older adults (intervention group n = 23, 75.7 \pm 7.8 years control group n = 14, 78.9 \pm 10.2 years. Gender not specified | Postural control and Quality of life with the WHOQOL-Bref questionnaire | 2 x 40min sessions (20mins walking) per week for 10 weeks on a flat surface treadmill (speed: 50% of 10-minute walk time speed progressed up to 100%). A control group was used. | Postural control: 6-minute walk distance: p \leq 0.001, 6-minute walk gait speed: p \leq 0.001, 10-minute walk gait speed: p \leq 0.001, Tinetti scale: p = 0.001 Quality-of-life scales: physical p = 0.01, psychological p = 0.002, self-assessed quality of life p = 0.01, the overall quality of life domains p = 0.002 |
| Pereira et al., 2020 | 37 institutionalized older adults (17 female, 20 male) Control group: n = 14 Intervention group: n = 23 | Postural control | 2 x 40min sessions (20mins walking) per week for 10 weeks on a flat surface treadmill (speed: 50% of 10-minute walk time speed progressed up to 100%). A control group was used. | Significant increase in all postural control tests: Borg balance scale: p= \leq 0.01 Gait speed: p= \leq 0.01 Short Physical Performance Battery: p= \leq 0.01 Timed up-and-go test: p= \leq 0.01 |

Kmph = Kilometres per hour, m = metres, Min = minutes, n = population chosen for study, p = significance, pre = before intervention, post = after intervention

4.5 Observed Variables

The variables observed within the sourced literature are described in the table below (Table 3).

Table 3. Observed Variables in the Articles Sourced for the Narrative Literature Review

| Variable | Description |
|--------------------------------------|--|
| Well-being and QOL | Well-being and QOL measures capture an individual's overall functioning and satisfaction, providing valuable insights for interventions and healthcare decisions to improve the overall QOL (Abey-Nesbit et al., 2021; Dehi et al., 2014; Pereira et al., 2021). |
| Fall Prevention and Postural Control | Fall prevention and postural control measures help identify risk factors, interventions, and strategies to enhance balance and stability, in turn reducing the risk of falls and improving physical well-being (Morrison et al., 2016; Walsh et al., 2018). |
| Gender | Considering gender allows for the exploration of potential differences and influences, helping to identify considerations, interventions, and healthcare approaches. |
| Incline Level | Incline level is significant in this review as it helps assess the impact of different incline levels on physical parameters, and potential risk factors, guiding recommendations for optimal outcomes and safety. |
| Intervention | Comparing interventions is crucial as it enables the investigation of the effectiveness and impact of specific treatments, strategies, or interventions on desired outcomes, providing evidence-based practice recommendations that can be applied to training guidelines. |
| Age | Age allows for the examination of age-related changes and impacts. This considers physical health and cognitive ability, helping to inform age-specific practices and recommendations. |
| Walking Method | The walking method allows for consideration of differences between controlled walking measures (treadmill) and natural outdoor settings, providing insight and considerations into effectiveness and safety precautions within the elderly population |

4.6 Results

4.6.1 Well-being and Quality-of-life

Flat surface and inclined treadmill walking on the QOL, and the well-being of elderly individuals were observed to have positive outcomes. Two studies incorporated a QOL questionnaire or survey as a measured variable following a treadmill walking intervention, both yielding significant results (Dehi et al., 2014; Pereira et al., 2021). It is to be noted that both Dehi et al. (2014) and Pereira et al. (2021) did not use incline settings. These findings are being included as no research was found utilizing an inclined treadmill training modality.

Dehi et al. (2014) reported improvements in all four measures within the QOL questionnaire for elderly participants. Notably, the study observed statistically significant increases in physical activity ($p = 0.004$), self-care ($p = 0.007$), cognitive function ($p = 0.004$), and life satisfaction ($p = 0.001$). A t-test analysis further confirmed these results with high significance ($p \leq 0.001$).

Similarly, Pereira et al. (2021) documented positive changes in four out of six measures assessed using the WHOQOL-Bref questionnaire. The study observed significant improvements in physical health ($p = 0.01$), psychological health ($p = 0.002$), self-assessed QOL ($p = 0.01$), and overall QOL ($p = 0.002$). However, no significant changes were found in the measures of social relationships and environmental health on the instrument. Additionally, even during a retest conducted one-month post-intervention, self-assessed QOL remained higher ($p = \leq 0.05$) in the intervention cohort (Pereira et al., 2021).

In a different context, Kuhman et al. (2018), examined the concept of biomechanical plasticity to increase walking difficulty from a flat surface to an inclined surface. The study found that more challenging walking tasks require greater magnitudes of biomechanical plasticity. This biomechanical plasticity is identified through decreased ankle joint output and increased hip joint output during walking, which indicate adaptations in walking mechanics. Larger magnitudes of biomechanical plasticity have been identified to possibly improve functional

benefits for older adults during inclined walking performances, suggesting the ability to enhance levels of QOL and improve ADL functionality (Kuhman et al., 2018).

4.6.2 Fall Prevention and Postural Control

Emerging evidence suggests that inclined walking can have contrasting effects on postural control and fall potential depending on the timing of the activity and subsequent rest periods. Studies conducted by Hill et al. (2020), Morrison et al. (2016), and Walsh et al. (2018) have all demonstrated an increase in postural sway, as measured through various assessments using a force platform, following bouts of treadmill walking. It is to be noted that Morrison et al. (2016) and Walsh et al. (2018) specifically focused on an inclined walking intervention, while Hill et al. (2020) used a control group walking on a flat surface treadmill while the intervention was declined walking.

Morrison et al. (2016) observed an increase in postural sway, as indicated by total path length, among individuals aged 60-69 (10.2 ± 0.7 to 12.1 ± 0.7 cm) and 70-79 (12.8 ± 1.1 to 15.1 ± 0.8 cm). Similarly, Walsh et al. (2018) reported increases in elliptical sway (1.38 ± 0.22 cm² to 2.35 ± 0.50 cm², $p = 0.01$), mediolateral movement (1.33 ± 0.03 to 1.40 ± 0.03 , $p = 0.01$), and anterior-posterior fluctuation (1.43 ± 0.02 to 1.46 ± 0.02 , $p = 0.04$) following an inclined walking intervention. Hill et al. (2020) also documented increased postural sway (52% to 98%), although the specific calculations for this data were not provided in detail, as the text primarily focused on the declined walking intervention group. It is also of note that Hill et al. (2020) observed that retesting after 30 minutes post-intervention, participants in the control group had returned to baseline measures, while Walsh et al. (2018) observed that 15 minutes of rest was insufficient following an inclined walking bout. Considering that both flat surface and inclined walking involve concentric muscle activation, it can be hypothesized that recovery time for inclined walking would likely exceed the 30 minutes observed in flat surface walking (Morrison et al., 2016; Walsh et al., 2018).

Additionally, two studies conducted on institutionalized elderly patients investigated the effects of treadmill walking on postural control, albeit using a flat surface treadmill (Pereira et al.,

2020; Pereira et al., 2021). Pereira et al. (2020) reported increases in several measures that correlate to postural control, with Berg balance scale (48.87 ± 8.49 to 52.13 ± 5.28 , $p = \leq 0.001$), gait speed (0.86 ± 0.27 to 1.07 ± 0.30 , $p = \leq 0.001$), short performance physical battery (8.26 ± 2.91 to 10.3 ± 2.20 , $p = \leq 0.001$), and a decrease in the timed up and go test (14.04 ± 6.36 to 11.36 ± 4.73 , $p = \leq 0.001$). Furthermore, these improvements remained highly significant during a post-intervention one-month follow-up assessment, with results barely changing. Pereira et al. (2021) also saw significant improvements in 6-minute walk test distance ($292.3\text{m} \pm 98.1$ to $341.0\text{m} \pm 114.9$, $p = \leq 0.001$), 6-minute walk test gait speed (0.81 ± 0.27 to 0.95 ± 0.32 , $p = \leq 0.001$), 10-minute walk test gait speed (0.86 ± 0.27 to 1.07 ± 0.30 , $p = \leq 0.001$), and Tinetti scale scores (20.9 ± 6.7 to 24.0 ± 5.5 , $p = \leq 0.001$) following treadmill walking on a flat surface. It is important to note that in both studies, measurements were collected immediately after the intervention, following 2-3 days of rest. These findings suggest that adequate rest time may play a crucial role in enhancing postural control measures and reducing the potential for falls. However, it is important to highlight that further research is needed to fully understand the relationship between inclined walking, postural control, and fall potentiality.

The findings taken from the current literature demonstrate that inclined walking initially decreases postural control, as evidenced by increased postural sway. However, after a sufficient rest period, the physical nature of the activity appears to enhance postural control and potentially decrease the risk of falls (Hilliard et al., 2008). This suggests a complex interplay between the timing of inclined walking, recovery time, and postural control outcomes. Future studies should explore the optimal duration of rest needed to restore postural stability following inclined walking and investigate potential differences between inclined and flat-surface walking interventions (Pereira et al., 2021).

4.6.3 Gender Differences

It was observed that genders saw differences in motor activity levels, though more research is necessary for this claim. In this review, a total of eight articles were selected, but only four of them provided the information regarding gender composition of the cohorts under investigation (Franz & Kram, 2014; Kuhman et al., 2018; Pereira et al., 2020; Walsh et al., 2018).

Interestingly, one of these studies solely reported the number of female participants, while not including any information about male participants (Kuhman et al., 2018).

While gender-specific findings were not explicitly reported, Kwee-Meier et al. (2018) did observe variations in muscle activity among females and males during uphill walking. Specifically, they observed differences in muscular activation in the gluteus maximus (GMAX), vastus medialis (VM), gastrocnemius medialis (GM), and soleus muscles. However, gender was not within the research parameters of the study where they primarily focused on researching age-related factors rather than gender-specific influences (Kwee-Meier et al., 2018). This resulted in limited investigation and exclusion of this data due to their perceived lack of relevance to the researchers.

The studies that did disclose the genders of the participants (Franz & Kram, 2014; Kuhman et al., 2018; Pereira et al., 2020; Walsh et al., 2018) also did not provide any comparative data between female and male individuals. Consequently, additional research is required to explore and investigate the observations made by Kwee-Meier et al. (2018) if there is a potential relationship between gender and muscle activity during inclined walking.

4.6.4 Incline Level

The research suggests that there could be a specific threshold level for the incline when it comes to treadmill walking training safely in the elderly population. However, further investigation is required to validate this and determine an optimal incline level. Among the eight studies reviewed, only one study incorporated a variable measuring the exertion levels of the participants. Kwee-Meier et al. (2018) conducted tests at two different gradients: 7° and 14° and observed a significant increase in perceived physical strain, as indicated by elevated Ratings of Perceived Exertion (RPE) values, among elderly participants at the 14° gradient compared to a younger cohort. Notably, this effect was not observed at the 7° gradient. It is important to highlight that only two studies in the review used a high level of incline as part of the intervention, namely 15.7% (Franz & Kram, 2014) and 14° (Kwee-Meier et al., 2018).

However, Franz & Kram (2014) did not include any measures to assess physical strain or cover potential adverse effects of the incline on the participants.

Additionally, three other studies implemented inclined walking interventions but with lower gradient levels: 1.20 m/s (Kuhman et al., 2018), 2° progressing up to 8° (Morrison et al., 2016), and 5.25% gradient (Walsh et al., 2018). More research needs to be conducted at various gradient levels to determine an optimal incline level for treadmill walking in the elderly population. Furthermore, exploring whether the appropriate incline level could decrease as age progresses would provide more valuable insights. By conducting studies across a range of gradient levels, researchers can better understand the impact of incline on elderly individuals during treadmill walking. Identifying the ideal incline level could help optimize the effectiveness of interventions while considering the potential physical strain experienced by older adults. Additionally, investigating the relationship between age and the appropriate incline level would ensure that interventions are tailored to individual capabilities and promote safe and beneficial exercise practices for the elderly population.

4.6.5 Lower Extremity Musculature and Joint Actions

It was observed that elderly individuals have compensatory movement patterns when walking at an inclined surface when compared to younger adults and standardized norms. Kuhman et al. (2018) observed that elderly individuals have decreased relative ankle % work when switching from a flat surface to inclined walking (41.9% to 34.4%), while relative hip % work also increases (41.3% to 46.1%). Similarly, Franz & Kram (2014) noted that older adults had 25% \pm 10 smaller peak extensor moments ($p = 0.001$), and 18% \pm 16 less power ($p = 0.014$), while also displaying 119 \pm 86% more peak power ($p = 0.013$) in the hip preceding the toe-off phase when compared to younger adults. Furthermore, Franz & Kram (2014) also observed that contrary to older adults, younger adults showed increased peak ankle extensor moments during flat surface versus inclined walking ($p = 0.003$). Stride length was also observed to be affected when switching from flat surface to inclined walking in the elderly (1.38m to 1.33m), while younger adults had no change between gradients (1.45m). Additionally, Kwee-Meier et al. (2018) noted that at a 7° incline elderly individuals displayed a significant increase in muscle activity in the

GMAX, rectus femoris (RF), VM, GM and soleus muscles, and at 14° the biceps femoris (BF) had a significant increase and an increasingly long activation during phases of gait. These findings suggest that due to the age-related loss of joint elasticity in the elderly, especially within the ankle joint, compensation occurs through the hip musculature joint actions to make up for the ankle (Menz & Lord, 2001). Furthermore, based on these findings, especially the BF long activation, it suggests that the elderly compensate for the lack of joint range by using their muscles to pull themselves uphill, instead of using a pushing action in the lower extremities like younger adults (Kwee-Meier et al. 2018; Menz & Lord, 2001).

4.6.6 Intervention

The research suggests that longer sessions of flat-surface treadmill walking have beneficial effects on the health measures of elderly individuals. However, it remains unclear which session length is effective for inclined walking training in the elderly population. Pereira et al. (2020) and Pereira et al. (2021) conducted studies involving institutionalized elderly patients who engaged in 20-minute flat surface treadmill walking sessions, along with warm-up, cool-down, and stretching activities, twice a week for a duration of 10 weeks. These interventions resulted in positive outcomes in terms of postural control and QOL. It is important to note that these studies included 2-3 days of rest immediately after each intervention as part of the protocol. Similarly, Dehi et al. (2014) observed positive results in the QOL of female elderly individuals who participated in 30-minute flat surface treadmill walking sessions, three times a week over six weeks. On the other hand, only one study included in the review used an intervention longer than 15 minutes while employing inclined treadmill walking. Walsh et al. (2018) used an intervention consisting of three 30-minute sessions, gradually progressing from a flat surface to a 5.25% incline.

It is worth noting that four studies reviewed in this context employed short interventions of 5 minutes or less for inclined walking (Franz & Kram, 2014; Kuhman et al., 2018; Kwee-Meier et al., 2018; Morrison et al., 2016). To establish the progressive effects of inclined walking training in the elderly population, further research using a similar approach to Dehi et al. (2014), Pereira et al. (2020), and Pereira et al. (2021) is needed. Specifically, studies incorporating

inclined walking training modalities for longer durations and assessing their impact on the health measures of elderly individuals would contribute to a more comprehensive understanding of this form of exercise in the elderly population.

4.6.7 Age

It is widely recognized that as individuals age, the detrimental effects of the process result in physical activity levels declining. This is a well-established understanding that physical abilities naturally decline with age (Plaut et al., 2021). Morrison et al. (2016) conducted a study involving a cohort of individuals aged 30 to 79, with participants grouped in 10-year increments. Their findings revealed a progressively detrimental impact as age increased, with the group of individuals aged 70 to 79 demonstrating a significant increase in fall risk compared to the other age groups. Importantly, the study also indicated that fall risk linearly increased across age groups as part of the natural ageing process, though not to a significant level outside of 70-79 (Morrison et al., 2016).

4.6.8 Walking Methods

It appears that declined walking paired with inclined walking could increase fall potential in elderly individuals. Morrison et al. (2016) conducted a notable study that examined the fall risk among elderly individuals immediately after engaging in a bout of inclined walking. Their research encompassed a comprehensive analysis of various factors such as standing balance, reaction time, leg strength, and gait ability. The findings indicated a noteworthy association between advanced age and susceptibility to falls, particularly beyond the age of 70. As participants progressed from the age of 30 to 79, the risk of falling progressively increased, with a significant elevation observed among individuals aged 70 and above. The 70-79 age group showed a decline in lower limb strength (32.3 ± 2 to 27 ± 1 kg) in knee extension as part of a long-form physiological profile assessment, slower reaction speed (256 ± 6 to 287 ± 8 ms) and increased postural sway via an increased path length performing a walking task. On the other hand, Hill et al. (2020) investigated that shed light on the impact of declined walking on fall risk in the elderly population. The research revealed that engaging in walking on a downward slope

could also heighten the susceptibility to falls. This finding was attributed to the eccentric exercise involved in the process, which led to a high level of fatigue in the muscles, especially those of the lower extremities. The researchers observed a prolonged heightened fall risk for up to several days following the intervention due to muscle weakness which was attributed to notably increased postural sway (+256%) and reduced concentric power (-33%). Further comparison, Walsh et al. (2018) observed that after prolonged surface level and uphill walking in the elderly population, 15 minutes of rest was not sufficient to reach pre-exercise levels for postural sway. Hill et al. (2020) also saw participants return to baseline readings 30 minutes post-exercise, though in a group walking on a flat surface treadmill. Findings by Morrison et al. (2016) and Walsh et al. (2018) are similar where fatigue levels immediately post-exercise have a detriment on postural sway, however, it is leaning towards that the rest required to recover from a bout of inclined walking compared to declined walking requires less time.

The collective implications of these three studies emphasize the critical importance of allowing sufficient recovery time for elderly individuals after engaging in inclined walking. It is essential to acknowledge that even though uphill walking in an outdoor environment offers valuable exercise opportunities, it could potentially exacerbate the risk of falls in certain circumstances. Particularly when an individual experiences fatigue induced by uphill walking and subsequently needs to navigate back downhill, the likelihood of falling might be further intensified (Hill et al., 2020; Morrison et al., 2016; Walsh et al., 2018). Therefore, it is crucial to consider these findings when deciding to use an inclined treadmill approach as it could provide appropriate precautions to ensure the safety and well-being of elderly individuals engaging in such activities. The reduction in rest time required also gives credence towards the treadmill walking modality where it more easily fits in and causes less of a detrimental effect to ADL tasks of the elderly.

4.6.9 Gym-based versus Home-based Intervention

One limitation identified in the research is the need for safety precautions when considering inclined treadmill walking and the elderly population. Kwee-Meier et al. (2018) identified this aspect by utilizing the RPE scale, which indicated that elderly individuals have the potential to

experience physical strain when performing bouts of inclined walking. This emphasizes the importance of implementing safety measures, especially in gym-based training interventions where staff, personal trainers, or other gym-goers are available to provide immediate assistance if required. On the other hand, a home-based intervention that lacks access to treadmills or other technological resources necessitates the exploration of alternatives such as community centres or outdoor activities like hiking or generally walking uphill. However, for such strategies to be effective and safe, it is crucial to engage in training sessions with a community, potentially with younger or more physically capable individuals because as previously discussed, the combination of inclined and declined walking poses increased safety concerns in the elderly population due to muscle fatigue.

It may be advantageous for future research to compare inclined walking on a treadmill with walking uphill in outdoor settings and assess potential differences in terms of QOL and physical effects. This comparison could provide valuable insights into the optimal modes of exercise for the elderly population and help guide the development of safe and effective training interventions.

Chapter 5: Systematic Review

5.1 Overview

This chapter contains a systematic literature review that follows from the narrative review and specifically investigates the impact of inclined walking on the biomechanics of the lower extremities, particularly joint moments and actions and muscle activation and impulses. By conducting an in-depth analysis, this review aims to present and synthesise the findings on how this training method affects the biomechanical function in the elderly population. Through comprehensive exploration of the scarce literature on this topic, valuable insights can be gained regarding specific biomechanical adaptations and potential benefits associated with inclined walking in older adults. The review contains studies that examine joint moments, actions, and related biomechanical variables during inclined walking, providing an overview of the biomechanical changes and compensatory patterns that occur in the lower extremities. By synthesizing the existing evidence, this review hopes to provide a better understanding of the impact of inclined walking on the biomechanics of elderly individuals, facilitating the development of effective interventions to enhance their mobility and overall physical well-being.

5.2 Introduction

Inclined walking is a challenging activity that could be encountered in the daily life of an elderly individual (Franz & Kram, 2013; Kimel-Naor et al., 2017), and the performance is influenced by factors such as the grade of the inclined surface or the presence of a slope (Choi et al., 2010; Lay et al., 2006). The understanding of how different surface levels and incline levels affect gait characteristics, lower extremity biomechanics, joint moments and actions, and muscle activation and impulses are crucial for objectively assessing gait alterations and planning effective training measures (Franz & Kram, 2014; Haggerty et al., 2014; Waanders et al., 2019; Waanders et al., 2020). Additionally, investigating the clinical implications of these

biomechanical differences between surface level and inclined walking is essential for developing rehabilitation strategies and prescribing appropriate exercise interventions in the elderly population (Alexander et al., 2017; Pereira et al., 2020). The ageing process often leads to declines in physical function and mobility, increasing the risk of falls and other musculoskeletal issues in older individuals, and can have severe consequences for the elderly, impacting their QOL and independence (Pereira et al., 2020). Therefore, exploring the biomechanical aspects of inclined walking and the potential effects on fall prevention, and how these can affect the general physical well-being of the elderly becomes important to better assist this vulnerable population (Ha et al., 2021; Pereira et al., 2020).

By examining biomechanical differences between surface level and inclined walking, researchers and clinicians can gain insight into the underlying mechanisms and potential benefits associated with inclined walking interventions. This knowledge can help to inform the development of evidence-based guidelines for exercise prescription and/or rehabilitation guidelines optimising interventions targeted at improving gait patterns, reducing fall risk, and enhancing overall functional capacity in the elderly population (Abey-Nesbit et al., 2021).

This systematic review aims to synthesize the existing literature on the biomechanical effects of inclined walking, specifically focusing on gait characteristics, lower extremity joint moments and actions, and muscle activation and impulses. By analysing the current research, this review seeks to provide an improved understanding of the biomechanical alterations induced by inclined walking and their implications for daily living. The findings of this review can serve as a foundation for future research and clinical practice in the field of gym-based training for elderly patients, geriatric rehabilitation, and guiding the development of effective interventions to enhance mobility, prevent falls, and promote the well-being of elderly individuals.

The researcher will review and analyse relevant studies that have investigated the biomechanical differences between surface level and inclined walking in the elderly population. The review will encompass studies examining joint kinetics and joint angle moments, gait speed and characteristics, muscle size, strength and activation patterns, postural control, and related biomechanical variables. This review aims to advance the current understanding of the

biomechanical effects of inclined walking and its implications on fall-preventative strategies, training guidelines, recommendations, and the overall physical health and well-being of the elderly population.

5.3 Literature Search

Because of the scarcity in the literature with only a single article sourced that measured inclined walking and the effects it has on dorsiflexion ROM in the elderly population, literature that measured ankle joint angle moments with inclined walking intervention was included.

5.4 Literature Table

All articles included in the systematic literature review are in the below table.

Table 4. Systematic Literature Review Table

| Study | Participants | Variables | Intervention | Results |
|--------------------|--|---|--|---|
| Choi et al., 2010 | 20 older adults (7 females, 13 males) and 14 younger adults (4 females, 10 males) | Gait speed, ratio of gait phase, hip joint angle, knee joint angle, ankle joint angle and centre of mass trajectory | 5 x sessions on a level and sloped inclined walkway | Level incline: Hip joint angle: Add: 20.61 ± 7.98 ($p = \leq 0.05$) Rot: 16.63 ± 4.80 ($p = \leq 0.05$) Knee joint angle: Flex: 65.54 ± 10.03 ($p = \leq 0.05$) |
| Franz & Kram, 2013 | 10 older adults (6 female, 4 male), age: 72 ± 5 yrs 10 young adults (5 female, 5 male), age: 25 ± 4 yrs | Stance phase electromyographic of gluteus maximus, biceps femoris, rectus femoris, vastus medialis, medial gastrocnemius, soleus, and tibialis anterior | 1 min x Walking at 1.25 m/s at each of seven grades ($0, \pm 3, \pm 6, \pm 9 / 0\%, 5.2\%, 10.5\%, 15.8\%$) in randomized order. | Older adults: smaller increases in medial gastrocnemius activity with steeper uphill grade compared to young adults (+136% to +174% at 9°). Hip muscles are disproportionately recruited leading to gluteus maximus approaching maximum isometric capacity in older adults at steep grades (73% maximum voluntary contraction vs. 33% maximum voluntary contraction at $+9^\circ$). |

| | | | | |
|-----------------------|---|---|---|--|
| Franz & Kram, 2014 | 10 older adults (6 female, 4 male) age: 72 ± 5 yrs 8 young adults (4 female, 4 male), age: 27 ± 5 yrs | Sagittal plane ankle, knee, and hip joint moments and powers | 4 x sessions of 2 mins walking at 1.25m/s at increasing gradients per session (0, 3, 6, 9 / 5.2%, 10.5%, 15.7%) | Young adults were observed to increase peak ankle extensor moments during uphill vs. level walking ($p = 0.003$) Older adults' ankle joint produced $25 \pm 10\%$ smaller peak extensor moments ($p = 0.001$) and $18 \pm 16\%$ less power ($p = 0.014$) than younger adults Older adults produced $119 \pm 86\%$ more peak power ($p = 0.013$) in the hip than younger adults preceding the off phase of inclined walking |
| Liu et al., 2018 | 42 older adults (22 females, 20 males), age: 69+ years | Endurance, Strength, Muscle size and fall prevention measures (6min walk) | Fed astaxanthin formulation or placebo then 3 x sessions per week for 40-60mins over 3 months. Treadmill at ~ 1.3 m/sec with periods at a high treadmill incline of 9–12% grade separated by periods of inclined walking at 5–7% grade | Greater endurance during inclined walking = $>50\%$ 6min walk distance = $>8\%$ Increase in maximal voluntary force in ankle dorsiflexion = $+14.4\% \pm 6.2\%$ increased tibialis anterior muscle cross-sectional area = $+2.7\% \pm 1.0\%$ No changes in the placebo group |
| Waanders et al., 2019 | 22 older adults, age: 65+ yrs (13 female, 9 male) 18 young adults (9 female, 9 male), age: 18-35 yrs | Bilateral ground reaction force and marker data and maximal voluntary eccentric, isometric, and concentric contractions for the knee extensors and plantarflexors | 9 x conditions of the 60s at three speeds (1.1, 1.4, and 1.7 m/s) at each of three gradients (-10%, 0%, and 10%) and right leg maximum voluntary eccentric, isometric, and concentric plantar flexor and knee extensor moment dynamometry | Older adults took shorter steps during inclined walking: 7.5% at 1.7 m/s^{-1} older adults exhibited a distal-to-proximal redistribution of positive leg joint work during flat and inclined walking ($P = \leq 0.001$). age-related differences: older adults exhibited smaller differences between their plantarflexors and hip flexors/extensors |
| Waanders et al., 2020 | 22 older adults (13 female, 9 male), age: 76 ± 5.7 17 younger adults (9 female, 8 male), age: 22.5 ± 4.1 | Lower-extremity moment-induced angular accelerations calculated for the hip and knee joints | 5 minutes treadmill walking at 1.2 m/s then 1 x minute at 1.4 m/s at each grade in a fixed order (0%, 10%, -10%) | Both groups were comparable: ankle moment-induced ipsilateral ($p = 0.774$) and contralateral ($p = 0.047$) hip accelerations. ankle moment-induced contralateral hip accelerations were smaller ($p = 0.001$) in an older adult subgroup ($n = 13$) showing larger hip extension moments in early stance. |

Add = Adduction, Rot = Rotation, Flex = Flexion, p = significance, min = minutes, m/s = metres per second, yrs = years

5.5 Observed Variables

The variables observed within the sourced literature are described in the table below (Table 5).

Table 5. Observed Variables in the Articles Sourced for the Systematic Literature Review

| Variable | Description |
|---------------------------|--|
| Joint Kinetics | Joint kinetics is critical in the context of this review as it provides insight into joint loading, biomechanical forces, and potential risks associated with inclined walking in a vulnerable population. Findings contribute to the development of safe and effective exercise guidelines, interventions, and strategies for fall preventive measures tailored to the needs of the older population (Choi et al., 2010; Franz & Kram, 2013; Franz & Kram, 2014) |
| Joint Moments | Assessing joint moments of the ankle, knee, and hip joints during inclined treadmill walking in elderly individuals is important for understanding biomechanical adaptation and potential stresses on these joints. This helps to inform gait retraining strategies, exercise protocols, and interventions aimed at reducing injury risk, improving mobility, and optimizing joint function and overall health in the elderly population (Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020). |
| Single and Double Support | Analysing the patterns of single and double-leg support during inclined treadmill walking in elderly individuals is important for assessing an individual's fall potential, postural control, and gait stability level. This provides insight into specific challenges faced by the elderly population during inclined walking and informs the development of exercise programs and targeted interventions (Franz & Kram, 2014). |
| Muscle Size and Strength | Assessing muscle size and strength from inclined walking provides insight into the impact of this modality on muscle development and potential functional improvements in the elderly. This aids in understanding how to recommend exercise interventions to optimize muscle size and/or strength in older adults, ultimately enhancing their independence, mobility, and overall well-being (Franz & Kram, 2014; Liu et al., 2018; Waanders et al., 2019). |
| Gait Speed | Walking on an incline suggests that gait speed, an important indicator of functional capacity, flexibility and/or mobility, may be |

| | |
|---------------|---|
| | influenced by this modality (Choi et al., 2010). |
| Stride Length | Walking on an incline may affect the stride length of the walking process. Inclined walking may lead to decreased stride length due to adjustments in gait patterns and/or muscle activation. This measure is important as it has implications for the biomechanics and walking ability of the elderly population (Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020). |
| Stance Phase | The stance phase is an important measure to understand how inclined walking influences the duration and characteristics of this phase. It helps to understand the activation and effort required to maintain balance and propulsion and assess how alterations in joint loading, muscle actions, and foot pressure distribution affect gait stability and fall risk (Choi et al., 2010; Franz & Kram, 2013; Waanders et al., 2020). |

5.6 Results

A total of 25 articles were initially found as displayed on the PRISMA diagram (Figure 2).

Duplicate articles were removed and narrowed the list down to 12 articles. This removal process was performed manually by the researcher due to the small number of article findings. One publication was excluded during the screening process as it was conference notes and not a journal article. Five more studies were excluded based on abstract evaluation because one used a cohort of participants ≤ 50 years of age, one did not use an inclined walking intervention, and three made use of prosthetics, robotics, and/or aiding devices outside of safety measures that were required by or used to assist participants in the walking process. The remaining six articles met the inclusion criteria and were obtained for this review. The results of this search can be viewed in the literature table (Table 4), as well as the PRISMA diagram (Figure 2).

5.6.1 Study Characteristics

Out of the six studies, there was a total number of 193 participants, which is broken down to 126 older adults and 67 young adults. All studies that made use of young adults did so in comparison to an elderly cohort within the same intervention study. Though, this total number of participants could be less than what is calculated as two researchers produced four articles

within this review and participation in trials obtained via similar methods. One researcher selected a cohort via phone interview process and did not discuss how the cohort was sourced in the other article, with participant numbers similar across the articles (Waanders et al., 2019; Waanders et al., 2020). The other researcher recruited older adult participants from senior mountain hiking and cycling groups local to Colorado, and similarly, did not discuss how the cohort was sourced in the other article, though, similarly, participation numbers were similar across the articles (Franz & Kram, 2013; Franz & Kram, 2014).

5.6.2 Study Design

One study was a double-blind randomized controlled trial (Liu et al., 2018), and five studies used a quasi-experimental design (Choi et al., 2010; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020).

5.6.3 Setting

Five studies were conducted within the United States of America (USA) (Liu et al., 2018; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020), and one study in South Korea (Choi et al., 2010). One study listed that the intervention occurred within controlled laboratory settings at the University of Washington Medical Centre and the Fred Hutchison Cancer Research Centre, and all exercise training was overseen by an American College of Sports Medicine certified exercise physiologist (Liu et al., 2018), and five studies did not include information regarding the trial setting.

5.6.4 Participant Characteristics

All studies focused on older individuals as the primary focus group of the study (Choi et al., 2010; Liu et al., 2018; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020), while those utilizing younger participants did so to compare to results gathered from the older cohort (Choi et al., 2010; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020). All studies used cohorts of female and male participants in both older and younger adult groups (Choi et al., 2010; Liu et al., 2018; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020). Three studies

used a cohort of >70-year-old adults (Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2020), while additionally in one study the males were > 70 years old but females were > 65 years old (Choi et al., 2010), and two studies used cohorts of 65+-year-olds (Liu et al, 2018; Waanders et al., 2019). While less important to this review, younger adults ranged from 18-35 years of age in one study (Waanders et al., 2019), and averaged approximately the mid-twenties across the other four studies, from 22.8 to 27 years of age (Choi et al., 2010; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2020).

5.6.5 Interventions

Five studies used an inclined treadmill for the intervention (Liu et al., 2018; Franz & Kram, 2013; Franz & Kram, 2014; Waanders et al., 2019; Waanders et al., 2020), and one study used an artificial inclined walkway made of wood at a width of 100cm, total length of incline at 240cm at a slope of 20° with an artificial gravel mat attached to simulate a real-world unstable surface as the intervention (Choi et al., 2010). For treadmill interventions, duration, inclination, and speed specifications were adapted based on the needs of the participants and the aims of the studies. In the study by Liu et al. (2018), the treadmill was set to an incline of 9-12% grade at a speed of ~1.3m/sec with recovery periods of 5-7% incline grade. Franz & Kram (2013) and Franz & Kram (2014) had the same treadmill settings across both articles with slope grades of 0%, 5.2%, 10.5%, and 15.7% incline gradient at a speed of 1.25m/s, with Franz & Kram (2013) including -5.2%, -10.5%, and -15.7% slopes. Waanders et al. (2019) used walking speeds of 1.1, 1.4, and 1.7 m·s⁻¹ and Waanders et al. (2020) used 1.4 m/s while both using the same treadmill grade settings at -10%, 0%, and 10% sloped gradients. One study used a training intervention of three sessions per week of 40-60 minutes over a period of four months with three months used for training in that period (Liu et al., 2018). Five studies used single or multiple days to obtain measurements with Franz & Kram (2013) using 1-minute of walking at each of the seven grades, Franz & Kram (2014) using four sessions of 2-minutes walking at each of the grades, Waanders et al. (2019) using nine conditions of 1-minute walking at each of the three speeds each of the three gradients, and Waanders et al. (2020) using 1-minute walking at each sloped

gradient in a fixed order. Choi et al. (2010) used 10 bouts of walking across the level inclined walkway and sloped inclined walkway at a speed self-selected by each participant.

5.6.6 Measures of Assessing Outcome

Liu et al. (2018) used magnetic resonance imaging to determine the cross-sectional areas of the TA muscle, and a custom-built isometric exercise apparatus to determine the contractile properties of the TA in ankle dorsiflexion. Four studies used motion analysis, three with an 8-camera motion analysis system (Franz & Kram, 2014; Waanders et al., 2019; and Waanders et al., 2020), and one with a 6-camera system (Choi et al., 2010). All studies that used the 8-camera system also measured ground reaction force data and used the results to quantify hip, knee, and ankle joint kinetics (Franz & Kram, 2014; Waanders et al., 2019; and Waanders et al., 2020). Choi et al. (2010) used the motion analysis data to measure the ratio of stance and swing phases, gait speed, pelvic angle, and joint angle of the lower extremities (ankle, knee, and hip). Waanders et al. (2019) also measured maximal voluntary concentric, isometric, and eccentric contractions for the knee extensors and plantarflexors using respective dynamometers. Franz & Kram (2013) measured the electromyographic activity of the GMAX, BF, RF, VM, medial GM, soleus, and TA of the stance phase in walking.

5.6.7 Outcomes

5.6.7.1 Joint Kinetics and Moments

In one study, no significant differences were found between older adults and the younger cohort in sagittal plane joint kinematics (Franz & Kram, 2014), while another observed significant differences in knee joint flexion between a level and sloped inclined walkway ($65.54^\circ \pm 10.03$ to $54.47^\circ \pm 13.86$, $p \leq 0.05$) and no significant differences in hip and ankle joint flexion (Choi et al., 2010).

Younger adults produced increased peak ankle extensor moments during inclined walking compared to level walking, which was absent from the older group ($p = 0.003$) (Franz & Kram, 2014). Waanders et al. (2019) observed younger adults showed plantarflexors as the largest relative contributor to total positive joint work ($50.4\% \pm 6.5\%$), while older adults showed the

hip flexors/extensors as the highest contributor ($45.5\% \pm 6.3\%$), followed by plantarflexors ($43.2\% \pm 5.9\%$). This relative contribution in older adults has an age-joint interaction effect showing there is a smaller difference between hip and ankle joint work compared to younger adults ($F_{1,84,76} = 8.38$, $P = 0.001$, $\eta^2 = 0.18$) (Waanders et al., 2019). As walking speed increases from slow to moderate, this age-joint interaction shifts relative muscle contribution from the ankle to the hip muscles (joint-speed: $F_{2,76,105.0} = 66.94$, $p = \leq 0.001$, $\eta^2 = 0.64$). Waanders et al. (2020) indicated older adults performed 13.9% less positive plantar flexor work and had 8.5% lower impulse in late stance than young adults and increased as the incline increased (+19.1% and +16.6%, respectively, $p = \leq 0.05$). Older adults generated $18\% \pm 16\%$ less peak power and produced $25\% \pm 10\%$ smaller peak extensor moments in the hip joint during inclined walking compared to the younger cohort (Franz & Kram, 2014). Older adults produced $119\% \pm 86\%$ more peak power in the hip immediately preceding the toe-off phase over the younger cohort when inclined walking ($p = 0.013$) (Franz & Kram, 2014). Regardless of inclined or levelled walking, older adults were observed to have more positive hip joint extension (+19%, $p = \leq 0.05$), and flexion (+15.85, $p = \leq 0.05$) than younger adults, but with comparable impulse levels of both actions (Waanders et al., 2020). Choi et al. (2010) observed a significant effect on hip joint angle through the frontal plane ($20.61^\circ \pm 7.98$ to $12.80^\circ \pm 3.89$, $p = 0.05$) and transverse plane (16.63 ± 4.80 to 13.45 ± 6.10 , $p = \leq 0.05$) when moving from a level to sloped incline. Waanders et al. (2020) saw no significant interaction effects between age and/or slope in the hip joint compared with the younger cohort. One study saw knee extensor moments differed significantly between the older and younger groups on both flat surface and inclined walking conditions (level: 0.24 ± 0.11 Nm/kg and inclined: 0.05 ± 0.07 versus level: -0.06 ± 0.08 Nm/Kg and inclined: -0.31 ± 0.08 Nm/kg, $p = 0.011$) (Franz & Kram, 2014), while Waanders et al. (2019) saw similar work rates between the groups at $11.3\% \pm 4.9\%$ in older adults and $9.5\% \pm 4.7\%$ in younger adults when inclined walking. Waanders et al. (2020) saw no significant interaction effects between age and/or slope in the knee joint compared with the younger cohort. Older adults produced $110\% \pm 67\%$ larger peak flexor moments during inclined walking and absorbed $246\% + 113\%$ more peak power than the younger cohort during mid to late stance ($p = 0.007$ and $p = 0.003$, respectively) (Franz & Kram, 2014).

5.6.7.2 Single and Double Limb Support

Older adults were observed to perform 16% less double support trailing positive joint work than the younger cohort when inclined walking ($p = 0.051$) (Franz & Kram, 2014), with no difference in double support duration between groups. During inclined walking older adults produced 119% +112% more trailing leg positive work using muscles that cross the hip during double support ($p = 0.012$), and 70% + 23% less single support positive work using muscles that cross the hip per step than the younger cohort ($p = \leq 0.001$) (Franz & Kram, 2014).

5.6.7.3 Muscle Size and Strength

Muscle size was measured in one study investigating the dorsiflexor muscle TA (Liu et al., 2018). TA cross-sectional area was observed to increase by $2.7\% \pm 1.0\%$, $p = \leq 0.01$, with no significant changes in the control group with an increase of $0.6\% \pm 1.2\%$, $p = > 0.6$ (Liu et al., 2018). Maximal voluntary force contraction of the TA saw a significant increase ($4.4\% \pm 6.2\%$, $P = \leq 0.02$), while the control saw no significant changes ($9\% \pm 5.6\%$, $p = > 0.6$) (Liu et al., 2018). Analysing the cross-sectional area (CSA) findings with maximum voluntary contraction (MVC) for specific force also saw significance (MVC/CSA: $11.6\% \pm 6.0\%$, $p = 0.05$), while the control saw no significant changes (MVC/CSA: $2.4 \pm 5.7\%$, $p = > 0.6$) (Liu et al., 2018).

Waanders et al. (2019) observed that MVC of the knee extensors was lower in older individuals compared to a younger cohort (age: $F_{1,36} = 28.42$, $p = \leq 0.001$, $\eta^2 = 0.44$), but this loss of strength differed by muscle action type (age-velocity: $F_{2,42,87.04} = 15.13$, $p = \leq 0.001$, $\eta^2 = 0.30$). Specifically, post hoc analyses highlighted a significantly smaller difference between eccentric and concentric muscle actions between the older and younger group ($P = \leq 0.05$).

Plantarflexor MVC was also observed to be lower in older adults compared to the younger cohort (age: $F_{1,36} = 13.44$, $p = 0.001$, $\eta^2 = 0.27$), however, the result was not affected by the type of muscle action (age-velocity: $F_{2,76,99.42} = 1.17$, $p = 0.320$, $\eta^2 = 0.03$). Franz & Kram (2014) observed that older adults had significantly weaker isometric strength in the knee (3.11 ± 1.05 N/kg versus 4.47 ± 1.34 N/kg, $p = 0.046$) and hip (1.49 ± 0.43 N/kg versus 2.36 ± 0.50 N/kg, $p = 0.003$) extensor muscles than the younger cohort.

5.6.7.4 Gait Speed and Stride Length

Gait speed was measured in one study and was found to decrease when a group moved transitioned from a level inclined walkway to an inclined walkway sloped in a left or right direction (Choi et al., 2010). A figure presented in the article depicts that both younger and older adult groups saw a significant decrease in gait speed from a level to a sloped gradient, however, the raw data is not provided. Data provided shows the younger group walked at 14.995 m/s and the older group at 13.542 m/s, and the introduction to slope had a significant effect on both groups ($p = 0.001$) (Choi et al., 2010). Franz & Kram (2014) observed older adults had a 10% shorter stepping range ($p = 0.051$), Waanders et al. (2019) observed a 7.5% shorter stepping range when walking at $1.7 \text{ m}\cdot\text{s}^{-1}$, Waanders et al. (2020) observed 3.7% shorter steps ($p = \leq 0.05$).

5.6.7.5 Stance Phase and Stance Phase Muscle Activity

Choi et al. (2010) observed that the ratio of stance phase was maintained at a constant rate across conditions and saw no significant differences between groups on a level incline or sloped incline. Franz & Kram (2013) saw stance phase activity of the ankle, knee, and hip extensor muscles all increase significantly as steeper incline gradients progressed in both age groups. Waanders et al. (2020) observed 5° greater hip flexion in the stance phase ($p = \leq 0.05$) and a 4.4° lower peak plantarflexion rate in late stance ($p = \leq 0.05$). Older adults showed lower EMG activity across all measured muscle groups compared to the younger cohort (136% versus 174% at a 9° incline) Franz & Kram (2013). At all inclined grades, older adults showed greater than twice the relative GMAX activation than the younger cohort and approached maximum isometric capacity at steeper grades (73% MVC versus 33% MVC at a 9° incline) Franz & Kram (2013).

Chapter 6: Discussion and Conclusion

The examination of inclined walking and its impact on the elderly population's well-being and fall prevention showed preliminary findings (Dehi et al., 2014; Pereira et al., 2020; Pereira et al., 2021), but further research is needed in these specific areas. While most of the research did not implement regular exercise sessions over extended periods, the findings from both the narrative and systematic review highlight the potential benefits of flat surface treadmill walking and inclined grade walking on the QOL and well-being of the elderly population (Dehi et al., 2014; Franz & Kram, 2013; Pereira et al., 2020; Pereira et al., 2021; Waanders et al., 2019). Additionally, one study that incorporated a 4-month training intervention using an astaxanthin formulation showed significant positive results compared to the placebo control group, indicating the potential influence of nutritional factors on the response to the inclined walking training modality in the elderly (Liu et al., 2018), and further research is needed in this area, also.

The common thread across the reviewed studies is the recognition of decreased muscle strength, impaired balance, and compensatory movement patterns in the elderly population during inclined walking leads to an increased risk of falls (Morrison et al., 2016; Rejeski & Mihalko, 2001; Waanders et al., 2019; Waanders et al., 2020; Walsh et al., 2018). Joint kinetics and muscle activation levels differ between older and younger adults, underscoring the age-related differences in walking ability and the need for compensatory strategies (Franz & Kram, 2013; Franz & Kram 2014). Generally, it was observed that most of the researchers across most of the studies aimed to address these variables due to their direct implications for fall risk and overall mobility in the elderly (Choi et al., 2010; Franz & Kram, 2013; Liu et al., 2018; Morrison et al., 2016; Waanders et al., 2019; Walsh et al., 2018).

Inclined walking on a treadmill has emerged as a promising modality for investigating the impact of different intensities of inclined walking on balance, gait, and other fall-related factors in older adults. Researchers can manipulate the incline angle and walking speed to create various levels of challenge, enabling systematic investigation of the effects (Haggerty et al.,

2014; McIntosh et al., 2006). The controlled environment of the treadmill provides more precise measurements and comparisons of variables than outdoor conditions, making it an ideal setting for studying gait and balance dynamics in older adults (Haggerty et al., 2014; McIntosh et al., 2006). One of the challenges in designing effective interventions for older adults is tailoring them to their specific needs. Further research is necessary to fully understand the effects of inclined walking treadmill-based interventions and to customize them to individual needs.

Interestingly, the measurement of dorsiflexion, a crucial aspect of inclined walking and a known contributing factor of fall potential in the elderly (Bok et al., 2013; Menz et al., 2006; Menz & Lord, 2001) has been underreported in the reviewed research. The sole study that incorporated dorsiflexion measurements highlighted the importance of including this variable in inclined treadmill intervention studies (Liu et al., 2018), emphasizing its impact on muscle activation patterns and overall gait mechanics (Afschrift et al., 2019; Liu et al., 2018).

To address these gaps and further advance knowledge surrounding this topic, future research should focus on exploring the nutritional aspects of the elderly in the general physical activity field, as well as under the influence of an inclined walking training modality. Additionally, further research is needed to expand on gender differences in EMG signals, and research utilizing an inclined treadmill modality should include measurement of dorsiflexion ROM should lower extremity biomechanics be the focus of the specific research. By investigating these areas, researchers can continue to improve the effectiveness of rehabilitation strategies and exercise prescriptions for the elderly population, ultimately enhancing their overall well-being and reducing fall potential. Additionally, while the focus on the effect of inclined walking on the elderly has primarily been on biomechanical findings, further investigations are needed to explore the potential impact of inclined walking on other aspects of well-being, such as social engagement, cognitive function, and psychological factors. Furthermore, there is a need to explore and ascertain the optimal parameters for inclined walking interventions, such as the ideal incline angle, duration, and frequency of sessions for an elderly individual. Customizing these variables based on individual characteristics, such as functional capacity and medical

conditions, could further enhance the effectiveness of training programs for the specific needs of an elderly person.

The reviewed research highlights the potential benefits of incline walking on various aspects of well-being, fall prevention, and biomechanical factors in the elderly population. However, further research is necessary to address the identified gaps and provide more robust evidence regarding the specific effects, mechanisms, and long-term sustainability of inclined walking interventions. By expanding the current understanding in these areas, healthcare professionals, exercise practitioners, and rehabilitation therapists can develop targeted strategies to mitigate fall risks, improve well-being, and promote healthy ageing in the elderly population.

6.1 Limitations

A limitation encountered during this dissertation should be taken into consideration in the interpretations of the findings. There was a scarcity of literature available on the topic being researched. A result of this limitation meant additional articles needed to be included in the systematic review to ensure the analysis was comprehensive. However, acknowledging these additional articles, they did not measure or focus on dorsiflexion ROM as a dependent variable, which may have had an impact on the specificity and/or depth of the discussion and conclusion drawn from the review. Future research should aim to address this limitation by expanding upon the literature on this topic and conducting more targeted investigations into the ROM of dorsiflexion.

6.2 Practical Recommendations

The importance of monitoring the elderly population during inclined walking on a treadmill was observed for the safety of each of the participants. One safety measure that was not thorough in the literature was the utilization of tools such as the RPE scale, appearing only in one article. This monitoring approach ensures that the exercise is performed at a safe level, preventing excessive physical strain and potential adverse effects (Kwee-Meier et al., 2018). However, this safety aspect poses a limitation to the training modality, as it suggests that certain elderly

individuals may not be able to engage in inclined walking alone, thereby restricting its availability and overall effectiveness (Kwee-Meier et al., 2018; Pereira et al., 2021).

To address this limitation, it is paramount for exercise practitioners to implement measures that enable the continuous monitoring of subjects, allowing for a comprehensive assessment of the physical strain experienced during inclined walking. By employing suitable techniques to gauge the level of physical exertion, practitioners can tailor the exercise intensity to the specific capabilities of each individual and ensure a safe and beneficial exercise experience. This approach not only mitigates the potential risks associated with intense physical strain but also optimizes the effectiveness of the training modality for the elderly population (Kwee-Meier et al., 2018). This was indicated when a significant increase in physical strain when transitioning from a 7° incline to a 14° incline was observed, specifically among older adults (Kwee-Meier et al., 2018). This finding highlights the importance of closely monitoring and adjusting the incline levels to accommodate the physiological limitations and capabilities of elderly individuals.

The findings of this paper for training intervention guidelines are preliminary, and further research is needed to better evaluate training recommendations for this modality on older adults.

The preliminary findings of this dissertation indicate that:

- Frequency of training should consist of 3-4 training sessions per week with adequate rest time between sessions to promote recovery (Dehi et al., 2014; Liu et al., 2018; Pereira et al., 2020; Pereira et al., 2021; Walsh et al., 2018). 15 minutes of rest immediately after a bout of inclined walking was observed to not be adequate for recovery to baseline levels (Walsh et al., 2018), though 30 minutes was adequate for flat-surface walking (Hill et al., 2020). For the safety of the participant, 60 minutes or more of rest should be considered immediately post-training before returning to daily life, and further evaluation considered by the practitioner.
- Because walking ability can be varied across older adults, practitioners need to identify the preferred walking speed of individuals. This can be achieved via 6-minute walk and/or 10-minute walk tests and assessing the distance travelled to indicate the regular gait speed of the individual (Kwee-Meier et al., 2018; Pereira et al., 2020; Pereira et al.,

2021). The identified speed is considered the preferred speed (baseline), where slower speeds are then recovered and increased speeds are used to increase training intensity (Kwee-Meier et al., 2018). This was generally observed to be ~1.3m/s for flat-surface walking and ~1.2m/s for inclined walking (Franz & Kram, 2013; Franz & Kram, 2014; Kuhman et al., 2018; Liu et al., 2018).

- Intensity should be light and proceed into moderate, i.e., 2-3 proceeding up to 5-6 on an RPE scale of 0-10 (Kwee-Meier et al., 2018).
- Training time should initially be short and gradually increase over time. Starting at 10-15 minutes total session time and progressing up to 30-60 minutes (Dehi et al., 2014; Hill et al., 2020; Liu et al., 2018; Pereira et al., 2020; Pereira et al., 2021). Individuals should undergo a familiarisation phase to inclined walking for 1-to-2 weeks of 1 minute of inclined walking to 2 minutes of recovery, and progress to regular training of 2 minutes of inclined walking and 1 minute of recovery (Liu et al., 2018). Total session time is inclusive of warm-up and cool-down phases of 5 minutes each both at a self-selected pace.
- The primary type of exercise is inclined walking using a treadmill or outdoor inclined surface. The recommended incline level is 9-15% grade (5° - 9°) for training (Kwee-Meier et al., 2018; Liu et al., 2018; Morrison et al., 2016; Walsh et al., 2018), and 0-7% grade (0° - 4°) for recovery (Liu et al., 2018).
- Astaxanthin, found in foods like salmon, prawns, and crabs (Ambati et al., 2014), was observed to have positive effects when combined with inclined walking training (Liu et al., 2018). Therefore, a recommendation could be made for participants to include these food sources in their diet to potentially enhance the benefits of the inclined walking intervention.

6.3 Future Research

This dissertation has uncovered several significant effects of inclined walking in the elderly population, but it is evident that more comprehensive research is required to fully understand the implications of this training modality on this demographic. While the current studies have

primarily focused on comparing younger adults to older adults and exploring the compensatory patterns that emerge between the two groups, there remain additional research areas that are awaiting investigation.

Among the limited research conducted so far, which measured the effects of inclined walking on physical and psychological testing, most studies have reported highly favourable outcomes. These positive results highlight the need for future researchers to explore deeper into the underlying mechanisms that are the cause of these effects. By doing so, researchers can uncover improved training recommendations and guidelines that cater to the unique needs and vulnerabilities of this ageing population.

Additionally, an area of research that requires attention is the impact of inclined walking on biomechanics and joint ROM in older adults. While studies have revealed observable changes in these aspects among younger individuals, it remains largely unexplored in the elderly population. Understanding whether inclined walking can slow down age-related loss of elasticity and restrictions in ankle ROM would be invaluable in developing targeted interventions to maintain mobility and functional independence and in turn bolster well-being and QOL.

Furthermore, gender must be considered as a variable in future research endeavours. Although there have been indications of differences in lower extremity muscle activity between males and females during inclined walking, this finding was only a statement and was not investigated any further. Clarifying these gender-specific responses is crucial for tailoring training approaches that account for potential physiological disparities.

In summary, further expanding the breadth and depth of research in these areas is of paramount importance. Such efforts will provide a comprehensive understanding of the effects of inclined walking on the elderly population and the findings will help form improved evidence-based recommendations and guidelines that optimize the health, mobility, and well-being of older adults.

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