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The Effectiveness of Pilates in Preventing Falls in Healthy Older Adults

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Thesis submitted to the National University of Ireland Galway

School of Health Sciences for the degree of

Doctor of Philosophy

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College of Medicine, Nursing & Health Sciences

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ABSTRACT

Falls are a major cause of morbidity and mortality in older adults and evidence suggests that fall rates are rapidly increasing likely due to an aging population, which is placing a significant financial burden on health care systems across the world. Falls present one of the highest risks for the older population and many factors contribute to the increased risk of falls and fear of falling in older adults, such as reduced physical activity and mobility, decreased muscle mass and balance and lack of walking. Rehabilitation and falls prevention exercises are required to help older adults improve their mobility and independence. Therefore, this research aimed to investigate the effectiveness of a Pilates intervention, that included a supplementary home-based exercise programme, to decrease the risk of falls in healthy older adults in Ireland.

A systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was carried out. A PICOS approach was adopted to set the inclusion and exclusion criteria and evaluate the outcome measures: mobility, functional mobility, fear of falling, gait, postural balance and the number of falls during the Pilates intervention programme. Twelve randomised controlled trials (RCTs) of Pilates interventions, including comparisons with control groups and other forms of exercise were included. Overall, there were 702 participants, with 308 allocated to Pilates groups, 316 to control groups and 78 to a three-arm exercise group. Pilates showed an effect in postural stability in the mediolateral sway comparison to control groups (MD = -1.77, 95% CI, -2.84 to -0.70, $p = 0.001$, heterogeneity: $I^2 = 3\%$), mobility (MD = 9.23, 95% CI, 5.74 to 12.73, $p < 0.00001$, 15 heterogeneity: $I^2 = 75\%$) and fear of falling (MD = -8.61, 95% CI, -10.16 to -7.07, $p < 0.00001$, heterogeneity: $I^2 = 88\%$). In relation to other exercises group, Pilates showed positive effects in functional mobility (MD= -1.21, 95% CI, -2.30 to -0.11, $p = 0.03$, heterogeneity: $I^2 = 80\%$), mobility (MD = 3.25, 95% CI, 1.46 to 5.04, $p < 0.0004$, heterogeneity: $I^2 = 0\%$).

The first and the second studies that are included in this thesis describe the mat Pilates intervention, including the supplementary 6-week home-based exercise programme, with the pre- and post-intervention testing. The first study examined the feasibility of a Pilates intervention for healthy older adults using the following

outcomes: functional mobility, mobility, fear of falling, physical activity, postural balance and the spatiotemporal parameters of gait for six participants. Exploratory results were reported of the 6-week intervention. The second study, a cohort study, used snowballing to recruit participants. With 32 eligible participants included in the study. The results participants with previous experienced of Pilates suggests that functional mobility ($p < 0.001$), mobility ($p < 0.001$), gait velocity ($p = 0.022$), swing time ($p = 0.049$), stance time ($p = 0.013$) and double support time ($p = 0.040$). Postural stability in the mediolateral ($p = 0.025$) and anteroposterior sway ($p = 0.037$), and Physical activity ($p = 0.017$) were positively affected after the 6-week mat Pilates intervention.

The third study of this thesis reports on the prospective, open-label randomised crossover study. This third study was carried out over a 7-month period, with a one-month washout period. Volunteer participants ($n = 61$) were randomly assigned to Group 1 (Control-Pilates) or Group 2 (Pilates-Control) for twelve weeks. The Pilates intervention included accessories and supplementary home-based exercises. The primary outcome measures were gait velocity, the postural stability parameter of mediolateral sway and fear of falling. The secondary outcome measures included cadence, stride length, step length, stance time, swing time, step time, double support time of gait, the postural stability parameter of anteroposterior sway, functional mobility, mobility and physical activity. The results of this twelve-week Pilates intervention indicated that Pilates had an effects in functional mobility ($p = 0.002$), mobility ($p = 0.001$), postural stability in the mediolateral sway ($p = 0.040$) and the spatiotemporal parameters of gait: cadence ($p = 0.019$), step time ($p = 0.028$), stance time ($p = 0.012$), and double support time ($p = 0.031$).

In conclusion, the Pilates interventions were found to improve functional mobility, mobility, gait, fear of falling and postural stability for the meta-analysis. The results of six- and 12-week Pilates intervention indicated that Pilates may reduce the risk of falls and suggests that Pilates interventions for healthy older people may change their functional mobility, mobility, postural stability and spatiotemporal parameters of gait. However, high-quality RCTs that include the number of falls during the intervention program and participants with and a without history of falls still needed. Further, Pilates intervention programmes with longer follow-up periods are required.

Special thanks to Mom and Dad,

for their love, faith, encouragement, support and generosity. Even when I was far away, they always trusted me, were willing to understand my path and encouraged me in all my wishes and decisions. Thank you, Mom and Dad, for always being positive and supportive of my life as a professor, especially during this hard period of the Covid-19 pandemic. Thank you for being patient and waiting so long for me to return home.

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This thesis would not have been possible without the support of many wonderful people who contributed to this research. I am especially thankful to the older adult participants in Galway for attending the Pilates classes, for their kindness and for making my long journey worthwhile. To my fellow international and Irish colleagues whom I have met at NUI during this journey, thank you all for the coffee breaks and conversations. Deep thanks to my friend Moira for the great times we shared, the distractions from my research and for making my stay in Ireland unforgettable. It is also a pleasure to thank my friends from Brazil; even from far away, they always stood by me and were patient and understanding of whatever I needed. Special thanks go to my family, some of whom had the opportunity to visit me in Ireland. Their warm hugs were essential for me.

Finally, I am grateful for the funding provided to me by Science Without Borders, contributions to the internationalisation of Brazilian higher education and the National Council for the Improvement of Higher Education-CAPES- Brazilian government.

DECLARATION REGARDING THE WORK

The thesis is all my own work and that I have not obtained a degree in NUI Galway, or elsewhere, on the basis of the work described in the thesis.

Signed: Larissa Donatoni da Silva

DISSEMINATION OF RESEARCH

Podium Presentation

- Donatonidasilva, Larissa. Caroline McIntosh. Agnes Shiel. A Randomised Controlled study of 12-weeks of Pilates on fall risk factors in healthy older adults, 2019. 24th Annual Congress of the European College of Sport and Science. ECSS. Prague, Czech Republic 2019.
- Donatonidasilva, Larissa. Caroline McIntosh. Agnes Shiel. The effect of Pilates on changes in gait patterns in healthy older adults: A Randomised Controlled Trial, 2019. 25th Congress of the European Society of Biomechanics. ESB. Vienna, Austria 2019.
- DonatonidaSilva, Larissa. Caroline McIntosh. Agnes Shiel. The effectiveness of Pilates on falls prevention in healthy older adults, 2016. Postgraduate Study Day in Ageing Research. Irish Gerontological Society (IGS), Dublin Ireland 2016.

Poster Presentation

- DonatonidaSilva, Larissa. McIntosh, C. Shiel, A. The effect of Pilates intervention of 6-week to prevent falls in healthy an older adult. In: College of Medicine, Nursing & Health Sciences (CMNHS), 2017 NUI Galway. Research day, 2017.
- L. DonatonidaSilva. Caroline McIntosh. Agnes Shiel. The effect of Pilates on falls prevention in a cohort of healthy older adults. In: XVIII Italian Society of Movement Analysis in Clinic (SIAMOC), 2017, Torino. Congresso della Società Italiana di Analisi del Movimento in Clinica. Torino, 2017. v. 18. p. 32-32.
- DonatonidaSilva, Larissa. Caroline McIntosh. Agnes Shiel. The effect of Pilates on falls prevention in a cohort of healthy older adults. In: 3rd Transatlantic Wound Science and Podiatrist Medicine Conference. Galway, 2017. v. 3. p. 35.

PUBLICATIONS OF RESEARCH

1. L. DonatonidaSilva.; Agnes Shiel; Jerome Sheahan; Caroline McIntosh. Six weeks of Pilates improved functional mobility, mobility, postural balance and spatiotemporal parameters of gait to decrease the risk of falls in healthy older adults. *Journal of Bodywork and movement of therapies (Elsevier). Manuscript accepted for publication available on DOI: https://doi.org/10.1016/j.jbmt.2021.06.014* Authors contribution: Larissa Donatoni da Silva: Conceptualization, Funding acquisition; Investigation; Methodology; Resources; validation, visualization, Project administration, Data curation; Formal analysis and Writing - original draft.
   Agnes Shiel: Supervision, Conceptualization, Methodology and review.
   Jerome Sheahan: Formal analysis and Writing -review & editing.
   Caroline McIntosh: Supervision, Conceptualization, Methodology and Writing - review & editing.

2. L.DonatonidaSilva.; Agnes Shiel; Caroline McIntosh. Pilates reducing falls risk factors in healthy older adults: a Systematic Review and Meta-Analysis. *Frontier in medicine. Geriatric medicine. Manuscript accepted for publication available on DOI: 10.3389/fmed.2021.708883.*
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   Agnes Shiel: Supervision and review.
   Caroline McIntosh: Supervision, Conceptualization, Methodology and Writing - review & editing

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   Agnes Shiel: Supervision, Conceptualization, Methodology and review.
   Caroline McIntosh: Supervision, Conceptualization, Methodology and Writing - review & editing.

LIST OF ABREVIATION

ABC Activities-Specific Balance Confidence Scale

ADLs activities of daily living

AGS American Geriatric society

ANOVA Analysis of Variance

AP anteroposterior

BAL balance training program

BGS British Geriatric society

BMI Body mass index

BOI Burden of Illness

C Comparators

CBT conventional balance training

CCGs clinical commissioning groups

CG Control Group

CI Confidence Interval

CINAHL Cumulative Index to Nursing and Allied Health Literature

cm Centimetre

COG Center of gravity

CoP Center of Pressure

C-P Control-Pilates

DGI Dynamic Gait Index

EC Eyes closed

EO Eyes open

F Family

FAB Advanced Balance Scale

FES Falls Efficacy scale

FES-I International Falls Efficacy scale

FRT Functional Reach test

GEE Generalised Estimating Equation

GP general practitioner

ICC inter-rater reliability

I Intervention

IPAQ International Physical Activity Questionnaire

Kg Kilogram

Kg / m2 Kilograms per square meter

L left

MWT-10 Meter Walking Test

MWT-6 Minutes walking test

MANOVA Multivariate Analysis of Variance

MD mean difference

METs Metabolic Equivalent of Task

Meta-Analysis

m meters

m/s meters per second

ML mediolateral

MoCA Montreal Cognitive Assessment

MVPA Moderate to vigorous physical activity

n number

NHS National health services

NICE National Institute for Health and Care Excellence

NUI National University of Ireland

O Outcomes

OAH old age homes

P Population

PAR-Q Physical Activity Readiness Questionnaire

PAAT Physical Activity Assessment Tool

P-C Pilates-Control

PEDro Database of Physiotherapy Evidence

PG Pilates group

PI principal investigator

PIL Pilates training

PNFG Pilates neuro-proprioceptive facilitation group

PRISMA Preferred Reporting Items for Systematic Reviews and

PROSPERO registered in the International Prospective Register of

Systematic Reviews

QOL quality of life

R right

RCTs Randomised controlled trials

REC Research Ethics Committee

sec seconds

s seconds

S Study design

SD Standard Deviation

SMD standardised mean difference

SPSS Software Package for the Social Sciences

steps/min minutes per steps

T Test-t

TUG Timed Up and Go test

UK's United Kingdom'

WHO World Health Organization

CHAPTER 1 INTRODUCTION

1.1 Pilates

The Pilates method, developed by Joseph Hubertus Pilates in Germany in the 1920s, was based on the concept called “Contrology”, which aimed to coordinate the balance of the body, mind and spirit. Pilates exercise focuses on concentration, strength and mobility (Pilates and Miller, 1845).

The Pilates Method is an exercise system that allows individuals to have better integration in their daily lives. Pilates correct the posture, rebalances the muscles, developing the body stability for a healthier and longer-lasting life (Camarão, 2004).

Initially, Pilates exercises were practiced by dancers, athletes and artists (Gallagher and Kryzanowska, 1999, p. 9). Pilates was influenced by hatha yoga, the Feldenkrais Method, Chinese medicine and fundamentals and physical therapy for mind and body centring based on mat Pilates and equipment exercises (Larkam and Nichols, cited in Sorosky et al., 2007).

Pilates exercises should be performed according to the principles. Pilates consists of six principles: breathing, centring, concentration, control, flow and precision (Robbins and Van Heauit-Robbins, 2012, pp. 12-13). It focuses on the concept of the ‘powerhouse’ (Eisen and Friedman, 1980). The powerhouse is also called ‘core stability’, ‘centre of strength’, or ‘core control’ (Key, 2013, pp. 542-543). It is a low muscle contraction resulting in a low-impact exercise while improving abdominal muscle strength (Jago et al., 2006) and strengthening the body from the deeper muscles to the peripheral muscles (Rodriguez, 2006). Muscle

contraction is categorised as static (isometric) and dynamic (isotonic); dynamic contraction happens when the muscle works concentrically and eccentric contraction occurs in faster movements (Isacowitz and Clippinger, 2011, pp. 40-41).

There are 34 movements and around 500 variations with the goals of strengthening, lengthening, flexibility and motor coordination (Pilates and Miller, 1945). Pilates can also include accessories: balls, bands, discs, foam rollers, rings, balance boards (Robbins and Van Heauit-Robbins, 2012, p. 16), small arcs and boxes (Lange, 2000). The foam roller and the ring focused on stability (Robbins & Van Heauit-Robbins, 2012, p. 17); for example, the hundred exercises with the ring between the ankles builds more stability in the inner thigh and places extra weight on the legs (Herman, 2009, p. 17). Elastic bands were used to increase resistance and were classified by colour (yellow, red, green, blue and black) from light to heavy (Herman, 2009, p. 19). An individual's skill at Pilates exercises can be improved at the beginner, intermediate and advanced levels (Herman, 2009, p. 11). Pilates is a low-impact exercise and changes in sequence and number of repetitions for each exercise promote joint tear prevention (Rodrigues, 2006). Previously, the goals of Pilates were to make the individual more capable of performing functional activities, raise their self-confidence and courage, relieve back pain, promote a positive night's sleep, improve sexual activity and reduce fatigue, discomfort and pain (Gallagher and Kryzanowska, 1999, p. 12).

There are no age limitations to practising Pilates (Isacowitz and Clippinger, 2011, p. 1). Pilates has been recommended to older adults in order to increase their muscle tone, enhance their posture and prevent bone deterioration (Gallagher & Kryzanowska, 1999, p. 10). Older adults and individuals with strong muscles may

have better functionality of the upper and lower limbs, as well as better functional performance and balance (Granacher et al., 2013).

Currently, Pilates is also widely used by physiotherapists for rehabilitation (Comunello, 2011), injury prevention and post-acute rehabilitation (Latey, 2002), particularly for back, knee, hip, shoulder and repetitive stress injuries. Pilates improves the body physically in general, as well as in the asymmetries seeking to improve balance and improve weakness or injuries (Herman, 2009, p. 11).

The goals of Pilates are to improve muscular strength, endurance and power (Lang et al., 2000; Sorosky et al., 2007; Herman, 2009, p. 11; Isacowitz and Clippinger, 2011, p. 1); achieve flexibility and mobility (Rodrigues, 2006; Sorosky et al., 2007; Herman, 2009, p. 11; Isacowitz and Clippinger, 2011, p. 1); increase endurance; correct coordination and posture; and balance alignment (Gallagher and Kryzanowska, 1999, p. 12). Motor learning improves core control, static and dynamic posture intralimb and interlimb coordination, aesthetic form, body awareness and static and dynamic balance (Lang et al., 2000).

1.2 Falls

The World Health Organization (WHO, 2007, p. 1) defines a fall as *'inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest in furniture, wall or other objects'*. In Ireland, 75% of all fall-related deaths occur in older people (250 deaths each year) (Strategy to Prevent Falls and Fractures in Ireland's Ageing Population, 2008, p. 02).

Worldwide, mortality rates are highest in adults over 60 years of age. Falls are the second leading cause of death from unintentional injuries after car accidents. Around 684,000 fatal falls arise each year. More than 80% of fall-related fatalities

occur in low- and middle-income countries, with the Western Pacific and Southeast Asia regions accounting for 60% of these deaths (WHO, 2021).

1.2.1 Cost burden

The cost of falls is considered to have a significant impact on the healthcare system. The cost has been estimated at GBP 2.3 billion a year for the United Kingdom's (UK's) National Health Service (NHS, 2017–2018), an increase of 30%–50% for adults aged 80 and older and the cost for falls prevention has been supported by clinical commissioning groups (CCGs) in the UK.

Irish information on the burden of illness (BOI) regarding falls among adults aged 65 years and older in Ireland showed that the estimated annual cost of falls and fractures were estimated to EUR 551 million by 2010. In 2020, the cost was expected to rise from EUR 922 to 1,077 million; and in 2030, the cost is expected to rise from EUR 1,587 to 2,043 million (Strategy to Prevent Falls and Fractures in Ireland's Ageing Population, 2008, p. 42).

1.2.2 Falls risk factors

The risks of falls for older adults are classified as intrinsic (e.g. muscle weakness, history of falls, gait and balance deficits), extrinsic (e.g. medication and polypharmacy) or environmental (e.g. home hazards) (Laffoy, 2008).

Risk factors for falls include being female, low body weight, age 80 years and older, falls in previous year or month, use of sedatives, lack of physical activity, mobility issues, lack of muscle strength in lower limbs, deterioration in balance when standing, walking and turning, impaired postural reflexes, vision and cognitive function and depression and anxiety (Pirker and Katzenschlager, 2017).

Previous studies found that postural instability is related to falls in older adults (Shumway-Cook and Woollacott, 2000; Borah et al., 2007; Liaw et al., 2009; Pua et al., 2017). Instability is associated with the process of ageing rather than the disease process and measures need to be selected to prevent the consequences of postural instability (Borah et al., 2007). According to Roman-Liu (2018) stability can be assessed by using the static balance test for postural control to determine an individual's predisposition to falls. The CoP is the primary measure of a stable posture and it can be measured as a parameter associated with the displacement of CoP from the central point, or the velocity of the CoP and in projection on the structure of the AP and ML sway (Roman-Liu, 2018).

Age-related changes in gait, according to Rose (2010, p. 198), decrease velocity, stride length, step length, step time, step frequency, swing time, swing phase and increases stance time, double support time, stride width and stance phase. Gait parameters are accurate for clinical assessment (Fulwider et al., 2005). Tasks related to gait changes have been identified as predictors of falls (Bridenbaugh & Kressig, 2011).

1.2.3 Evidence of Pilates Effects on Falls

The popularity of Pilates has increased over the past ten years. Pilates exercise has been studied to determine whether Pilates can decrease the risk of falls (Moreno-Segura, 2018) in older adults (Irez-Babayigit et al., 2011; Bird et al., 2012; Pata et al., 2014; (Badiei et al., 2017; Roller et al., 2018).

A study by Irez-Babayigit et al. (2011) found that 12 weeks of Pilates training provided for one hour three times per week, was effective for reducing the number of falls in older women. There was a significant difference in the Pilates group when

compared to the control group ($p < 0.05$) over the 12 weeks of intervention in relation to improving participants' dynamic balance, flexibility, reaction time and muscle strength. The Pilates exercises included accessories of Pilates intervention which the author divided into three parts, such as four weeks of mat exercises, four weeks with thera-band exercises and four weeks with ball exercises.

Pilates has been found to decrease the fear of falling in individuals with chronic lower back pain (Cruz-Diaz et al., 2015), in healthy participants (Badiei et al., 2017) and in post-menopausal women (Aibar-Almazan et al., 2019). Among the effects noted in these studies, it has been observed that Pilates improves balance in older adults.

A crossover randomised controlled study conducted over 16 weeks, with a washout period of six weeks, investigated static and dynamic balance after a period of five weeks of intervention. An improvement was found in participants' static and dynamic balance following the Pilates intervention. No significant difference was observed between the Pilates and control groups. The author concluded that from the washout period, participants improved neuromuscular adaptation (Bird et al., 2012).

A quasi-experimental study design showed better balance confidence, postural stability and mobility for the risk factors associated with falls. Participants performed exercises to activate the central muscles and control breathing in the sitting and standing positions with the chair; accessories such as bands were also included. The results showed significant differences in the Time Up and Go test ($p < 0.001$) and the 180 test ($p = 0.002$) after eight weeks of Pilates intervention in 32 participants aged 60 years or older. Ten of the participants included had postural stability impairment in the pre-test. Among the 27 participants analysed, the TUG

showed that 20 participants had scores of more than ten seconds (pre-test). The post-test scores showed that seven participants still needed more than ten seconds to complete the test. Four participants reported one to three falls in the previous six months on the pre-test. After four weeks of participation in the programme, one fall was reported. After week eight, no falls were reported. However, the implications of the study were that not all participants returned their falls diary to the principal investigator (PI) (4 weeks: 88.5%; 8 weeks: 77.1%), which means that the results were inconclusive in terms of whether 4 weeks or 8 weeks of Pilates was enough to prevent falls among the participants. Furthermore, the study did not have a control group to compare the results during the programme, and thus, the researchers concluded that there were ceiling effects that should be accounted for (Pata et al., 2014).

In a randomised controlled trial study of Pilates exercises using only a reformer equipment, classes held once a week for 10 weeks were shown to decrease the risk of falls in adults older than 65 years of age who were at risk of falls. Participants were allocated randomly to the Pilates intervention (n = 27) and control (n = 28) groups. The Pilates group showed improvement in balance, functional mobility, balance self-efficacy and ankle dorsiflexion. Participants who were more functional had greater improvements in static and dynamic balance and the improvement of speed was related to increased strength. According to the authors, the limitations of the study were that the participants were not asked to record their falls in a fall diary; however, these participants were asked to recall the number of falls since the pre-test when they completed the post-test, so there may have been errors in counting (Roller et al., 2018). No falls were reported in the study, which could be attributed to missing data.

However, more studies are needed to provide evidence on the effect of Pilates on falls prevention; Pilate's exercises have not yet been recommended in any guidelines and organisations for preventing falls.

1.2.4 Evidence of Pilates Effects on Spatiotemporal Parameters of Gait

Previous studies have identified the spatiotemporal parameters of gait in neurological impairment (Shea and Moriello, 2014; SuYeon, et al., 2016; Kalron et al., 2017) and healthy individuals (Newell et al., 2012; Choi et al., 2019).

Pilates studies have shown an effect on walking speed after training (Newell et al., 2012; Shea and Moriello, 2014; SuYeon et al., 2016; Kalron et al., 2017). For instance, Newell et al., included healthy subjects for eight weeks of Pilates training albeit with a small sample size of just nine participants aged 60-76 (Newell et al., 2012). Improvement in the velocity variable was observed in the first three months; however, the gait speed decreased by 0.8 cm/s after six months. Despite the long-term nature of the intervention, that is, Pilates classes with equipment, one participant with a right-side ischemic stroke (male, aged 67, case study) was included. This participant also received botox therapy, however experienced complications, requiring 6 weeks of care for sepsis, kidney stones and acute renal failure, due to which the participant had to discontinue the rehabilitation. In addition, the training included different treatments such as physiotherapy (3 months) and occupational therapy (OT) (3 months) and in the following month both treatments took place only once per week (Shea and Moriello, 2014).

After eight weeks of mat Pilates training three times per week, the poststroke participants (n=20, chronic hemiplegia) showed improvements to gait such as in velocity and stride length (SuYeon et al., 2016).

Pilates exercise improved the stride length variable in subjects with neurological impairment (Shea and Moriello, 2014; SuYeon et al., 2016). A recent study included n = 22 healthy older women and found that individuals improved step and stride length after 10 weeks of Pilates training (thirty minutes, twice a week). Within this study there was a lack of a control group for comparison. However, there were no causal effects and the participants showed that their velocity gait scores were high on the pre-test and possible ceiling effects occurred (Choi et al., 2019).

1.3 Gaps in Pilates Studies

- ✓ There are a limited number of studies that evaluated fear of falling in healthy subjects.
- ✓ There are a limited number of studies that included the falls diary for the participants to record their falls in during the programme.
- ✓ Only two studies evaluated spatiotemporal gait in healthy subjects with no group comparison (Newell et al., 2012; Choi et al., 2019).
- ✓ There are different types of Pilates methods included in the studies: equipment, only mat Pilates and accessories. Some studies also included a mix of additional techniques.
- ✓ There are limitations in randomised controlled trial studies; primarily small sample sizes are used, there is a lack of methodological quality and rigour and the short-term nature of the programmes makes it difficult to assess the outcomes.

In this context, the following research questions arise:

1.4 Research questions

What is the strength of the evidence-base for Pilates in falls prevention?

Does the traditional Pilates programme of six- and twelve-week programme (Pilates training compared to control group) with a supplementary at-home programme effectively improve clinical-functional, biomechanical parameters of balance and gait in adults age 65 years and older?

1.5 Hypothesis of the Research

Traditional Pilates training with a supplementary at-home program for the six and twelve-week will improve clinical-functional, biomechanical parameters of balance, gait to decrease the risk of falls in healthy older adults.

1.6 Aim of the Research

The aim of the research was to evaluate the effects of Pilates training with a supplementary at home program for the pre-test and post-test of six-week and the effects of twelve-week and compared to control group (no activity) on falls risk measures; clinical-functional, biomechanical parameters of balance and gait in healthy older adults over 65 years of age.

To achieve the central theme of the thesis, the set of three objectives and the development of the three studies are presented below.

1.6.1 Aim (Systematic Review and Meta-Analysis)

The aim of this systematic review and meta-analysis is to assess the strength of the evidence for the effectiveness of Pilates in falls prevention in minimising falls risk factors for the following outcome measures; mobility, functional mobility, fear of falling, gait, postural stability and falls recorded during the Pilates intervention.

1.6.2 Aim (Feasibility Study)

The aim of the feasibility study was to trial the instruments and methodology for the subsequent studies and to determine whether traditional Pilates of a six-week duration, with a supplementary at home program.

1.6.3 Aim (Cohort and Randomised studies)

This study investigated whether a Pilates intervention of six weeks with a supplementary at-home program for the pre- and post-test and to determine whether the mat Pilates with accessories intervention and a supplementary at home of twelve-week program were effective in reducing falls risk factors in older adults (≥ 65 years). The study aimed to identify whether mobility, functional mobility, spatiotemporal gait parameters, postural stability, fear of falling and physical activity

1.7 Thesis Layout

The thesis is composed of six chapters (See figure 1).

Chapter 1 contains an introduction to Pilates exercises, along with the goals individuals have when they do Pilates and the benefits of doing Pilates. This chapter also references studies on Pilates and identifies the aims of each study and gaps that exist in the current research literature regarding falls, gait and balance in older adults. Finally, chapter 1 addresses the goals of the research, the layout of the thesis and the research questions.

Chapter 2 comprises of a systematic review and meta-analysis of the research literature. This chapter includes randomised controlled trials in Pilates studies that earned a high score on the PEDro scale. The meta-analyses explored the effectiveness of Pilates in managing fall risks.

Chapter 3 describes the feasibility study of the methodology. A non-experimental study was suitable for identifying variables, refining assessments, addressing questions and revising exercises.

Chapter 4 focuses on the cohort study. This study of six-week intervention evaluated the measures on the risk of falls in healthy older adults post mat Pilates training with supplementary training at home.

Chapter 5 presents the randomised crossover study. This study was a prospective, open label crossover trial design that was implemented during a seven-month period with a one-month washout period (no activity) programme.

Chapter 6 General Discussion and findings

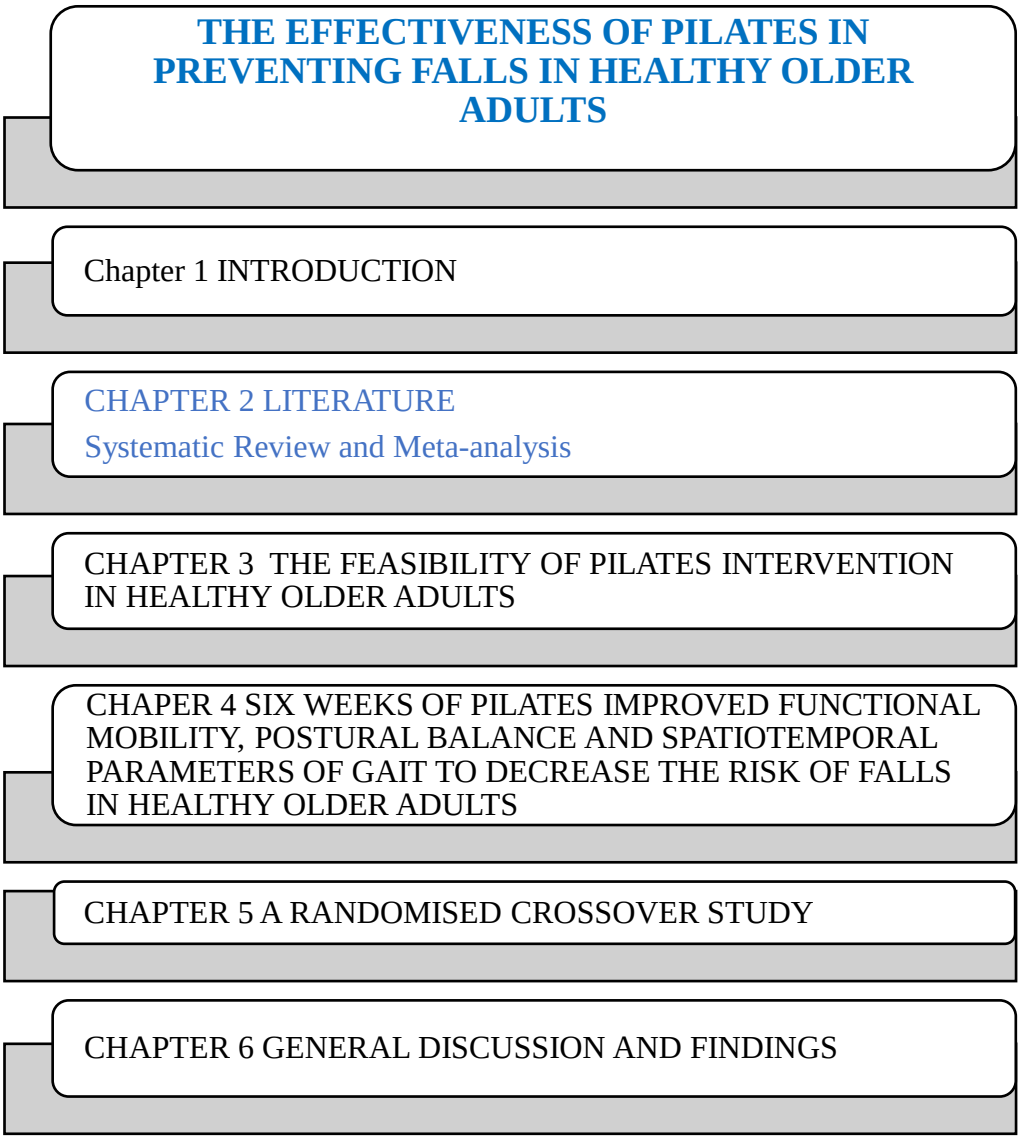

Figure 1 Layout of the thesis

CHAPTER 2 LITERATURE PILATES REDUCING FALLS RISK FACTORS IN HEALTHY OLDER ADULTS: A SYSTEMATIC REVIEW AND META-ANALYSIS

Published on Frontier in medicine. Geriatric medicine.
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Abstract

Background: The main theme of this systematic review and meta-analysis was to synthesise the evidence of randomised controlled trial of evidence of Pilates intervention, in comparison to control groups and other forms of exercise, for falls prevention in healthy older adults.

Methods: The following electronic databases were searched up to October 2020; EMBASE, Scopus, Google Scholar, MEDLINE (Ovid), Science Direct, Cochrane and CINAHL. The recommendations of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses were followed. A PICOS approach was adopted as a framework to formulate the research question and set the inclusion and exclusion criteria. Participants were healthy older adults, defined as older adults who have maintained functional ability, including participants of both genders, those with a falls history, non-fallers, and individuals who were considered to be sedentary or active. Randomised controlled trials, written in the English language, published within the last decade, were included if they focused on specific outcome measures to decrease falls risk; functional mobility, mobility, fear of falling, gait and postural stability. The PEDro scale was used to assess risk of bias.

Results: There were 12 studies included in this review. In total, 702 healthy older adult participants were included. Pilates showed an effect on postural sway in the

ML direction in comparison to control groups (MD = -1.77, 95% CI, -2.84 to -0.70, p = 0.001, heterogeneity: I^2 = 3%), mobility (MD = 9.23, 95% CI, 5.74 to 12.73, p < 0.00001, heterogeneity: I^2 = 75%) and fear of falling (MD = -8.61, 95% CI, -10.16 to -7.07, p < 0.00001, heterogeneity: I^2 = 88%). In relation to other exercises group, Pilates showed positive effects in functional mobility (MD= -1.21, 95% CI, -2.30 to -0.11, p = 0.03, heterogeneity: I^2 = 80%), mobility (MD = 3.25, 95% CI, 1.46 to 5.04, p < 0.0004, heterogeneity: I^2 = 0%). No evidence of an improvement was found between the groups for dynamic gait index (MD = 2.26, 95% CI, -0.05 to 4.56, p = 0.06, heterogeneity: I^2 = 86%), anteroposterior directions of balance (MD = -1.58, 95% CI, -3.74 to -0.59, p = 0.15, heterogeneity: I^2 = 51%) and functional mobility when compared to control groups (no exercise) (MD = -1.24, 95% CI, -2.48 to -0.00, p = 0.05, heterogeneity: I^2 = 87%).

Discussion: Pilates may be effective in decreasing the risk of falls in older adults. Pilates intervention was found to improve functional mobility, mobility, gait, fear of falling and postural stability and therefore there is some evidence to suggest that Pilates reduces certain risk factors for falls in healthy older adults. However, there is an absence of high-quality evidence in regards to the impact of Pilates on reducing falls and further robust RCTs are needed.

PROSPERO registration number CRD42021206134.

Keywords: falls prevention, older adults, balance, gait, mobility.

2.1 Introduction

A fall is '*an unexpected event in which the participant comes to rest on the ground, floor, or lower level*' (Lamb et al., 2005, pp. 1618-1622). Falls are a leading cause of morbidity, mortality, functional deterioration, hospitalisation, institutionalisation and pose a significant financial burden to health and social care services across the globe (Masud & Morris, 2001). It is estimated that, of the 646,000 deaths following falls each year, more that 80% occur in low and middle-income countries (World Health Organization - WHO, 2018). The occurrence of falls is known to increase with advancing age; from 18% in young adults to 21% in middle age and 35% in older adults (Talbot et al., 2005). The middle-aged population has been shown to have the highest percentage of injuries (70.5%) particularly in the knees, while older adults most frequently incur injuries from the head to the knee (Talbot et al., 2005). In relation to gender, evidence suggests that women (20.1%) are more likely to fall than men (18.2%) (Bhangu et al., 2017). Thus, women have the highest frequency of injuries across all age groups (Talbot et al., 2005).

The aging process is associated with decreased walking ability and walking speed. In individuals between the ages of 25 and 75 years, it is known that muscle power declines by 49% and muscle strength declines by 33% in this period (Grimmer et al., 2019). In older adults, the number of steps taken daily and walking speed were reduced by 75% between the ages of 60 and 85 and the falls per number of steps taken per day increases by 800% (Grimmer et al., 2019).

The Pilates method was developed in the 1920s by Joseph Hubertus Pilates and based on 'Contrology' which aimed to coordinate the balance of the body, mind and spirit. The Pilates method also focused on concentration, strength and mobility

(Pilates & Miller, 1945). Pilates has been shown to improve lower limb muscle strength, static and dynamic postural balance and functional mobility after completion of a 12-week programme (Oliveira et al., 2015). Pilates intervention has also been shown to decrease the fear of falling in post-menopause women (Hita-Contreras et al., 2016; Aibar-Almazán et al., 2019), older adults (Badiei et al., 2017) and in participants with low back pain (Cruz-Diaz et al., 2015). Other techniques such as Yoga and Tai Chi exercises have also been suggested to improve balance and prevent falls (WHO, 2007).

Several previous systematic reviews (Bullo et al., 2015; Enger et al., 2016; Moreno-Segura, 2018; Rodacki et al., 2018; Pucci et al., 2019) have reported on the effectiveness of Pilates. The practice improves health status, balance, muscle strength, flexibility, functional autonomy, muscle endurance, body composition and aerobic endurance (Pucci et al., 2019), functional capacity to perform daily living activities (Bullo et al., 2015) and quality of life (Bullo et al., 2015; Oliveira et al., 2015; Moreno-Segura, 2018). A previous meta-analysis of Pilates included ten studies with different subjects, such as healthy participants, those with a stable but chronic disease and Parkinson's disease. The analysis showed improvements in muscle strength and static and dynamic balance in older adults (Bullo et al., 2015). Previous systematic reviews have investigated the improvement in balance after Pilates (Bullo et al., 2015; Moreno-Segura, 2018; Rodacki et al., 2018) and the prevention of falls in older adults (Barker et al., 2015; Moreno-Segura, 2018). However, specific task training has been shown to improve balance more than Pilates-only groups (Moreno-Segura, 2018).

A recent meta-analysis of Pilates found improvement in postural stability in older adults (Casonatto et al., 2020; Rodacki et al., 2018). The authors included

randomised controlled trials (RCTs), quasi-experimental and crossover designs studies and found that only four out of fifteen studies measured static balance. The author suggested that mat-based Pilates exercises should be performed for forty minutes, three times per week for five weeks, or two or three times per week, to improve balance (Rodacki et al., 2018). However, Enger et al. (2016) argued that Pilates studies must also be of good quality, feature control groups and follow-up and make use of the more rigorous randomised controlled trial methodology. Bueno et al. (2018) suggest that more evidence is needed to judge the effects of mat Pilates on other physical functional measures in older adults.

Systematic reviews and meta-analyses in this field are important because they summarise the empirical evidence and analyse the results of Pilates intervention studies. They summarise information with regard to the effectiveness of Pilates RCTs for health care professionals which, might help to inform them and their clinical practice of the benefits of Pilates interventions for older adults. However, previous meta-analyses on the effectiveness of Pilates in falls prevention have shown that studies are still lacking and there is no definitive evidence on Pilates interventions in reducing/ preventing falls. Furthermore, it is still unclear whether postural balance and gait can be improved with Pilates intervention. Regarding gait, there is a distinct lack of data concerning the potential impact of Pilates intervention on the spatiotemporal parameters of gait in healthy participants, and there is a dearth of evidence from RCTs and systematic reviews. Relating to balance, a previous meta-analysis did not separate the measures of postural balance for fall risk, such as mediolateral and anteroposterior parameters and fear of falling, in healthy participants. It is important to address and clarify these fall factors to reduce any knowledge gaps for future researchers.

Further improvements in the clinical practice of Pilates for specific age groups and guidelines are needed in the context of Pilates, since broader falls prevention guidelines are available. Therefore, it is necessary to include the following in meta-analyses: randomised clinical trials (RCTs) in evidence-based Pilates practice; falls protocol for longer follow-up; and recording falls during the intervention (to measure any reduction in the incidence of falls during the intervention group program). The research question asked whether Pilates training reduces the risk of falls in healthy older adults, defined as older adults who have maintained functional ability, including participants of both genders, those with and without a fall history and those considered sedentary or active.

The main aim of this systematic review and meta-analysis was to synthesise the evidence of RCTs of Pilates intervention in comparison to control groups (no exercise) and to other exercises that focused on reducing the risk of falls by improving falls risk factors for the following outcome measures; mobility, functional mobility, fear of falling, gait, postural stability and falls recorded during the Pilates intervention.

2.2. Methods

This systematic review and meta-analysis followed the general guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). The protocol for this systematic review is registered in the International Prospective Register of Systematic Reviews (PROSPERO) number CRD42021206134.

2.2.1 Eligibility criteria

The studies selected met the following inclusion criteria using PICOS:

1) Population (P): Healthy older adults 60 years of age and older (male and female).

2) Intervention (I): All Pilates interventions, including mats, accessories and equipment.

3) Comparators (C): A comparison of Pilates training with parallel groups, including a control group with no intervention and a control group with other exercises.

4) Outcomes (O): Pre- and post-tests with regard to fear of falling, mobility, functional mobility, gait and postural stability by platform.

5) Study design (S): RCTs written in the English language and dated between 2010 and 2020.

Not all studies included were necessarily aimed at evaluating the effects of Pilates in preventing falls in older adults. This was due to a lack of studies that investigate the effect of Pilates on falls prevention specifically.

The exclusion criteria were: participants with neurological impairment or orthopaedic conditions such as lower back pain; the use of dynamic balance to evaluate balance and with no platform used for postural stability and non-RCT studies, such as semi- or quasi-experimental studies.

2.2.2 Search strategy

Electronic databases EMBASE, Scopus, Google Scholar, MEDLINE (Ovid), Science Direct, Cochrane and the Cumulative Index to Nursing and Allied Health Literature (CINAHL), were searched until 30th of October 2020.

The following search terms were used: Pilates AND healthy older adults, OR elderly OR aged, fall prevention OR risk of fall, fear of falling, postural balance OR balance, functional mobility, gait OR spatiotemporal parameters of gait AND randomised controlled trial.

2.2.3 Study selection

The Covidence systematic review component of Cochrane 1.0 extraction was used for importing citations, managing screening and data extraction by the reviewers (www.covidence.org).

The citations were imported into the Covidence systematic review software where any duplicate papers were excluded. Titles and abstracts were screened by two independent reviewers (LD and CM). Any disagreements between the reviewers were mutually resolved to reach a consensus. Potentially eligible articles were then reviewed in full text by two authors (LD and CM) and any disagreements were mutually resolved to reach a consensus.

2.2.4 Data extraction

Data were extracted independently by two reviewers (LD and CM) in Covidence. Consensus was reached at a later meeting between the two authors. Data extracted included participant demographics (age and sample size), study details (author, year, country), study design, setting or recruitment, aim, intervention groups and inclusion criteria. Pilates intervention description (material, duration and times per week of intervention), participants analysed, findings and recommendations.

2.2.5 Outcome Measures

The primary and secondary outcomes selected are associated with a decreased fall risk in older adults. Functional mobility: The TUG test is a sensitive and specific tool to identify community-dwelling adults who are at risk of falling, including older adults who have balance impairments and who live independently within a community. Older adults who scored ≥ 13.5 seconds to perform the TUG were classified as fallers with an overall accurate prediction rate of 90% (Shumway-Cook, 2000).

The parameters of postural stability: The anteroposterior parameter was associated with a history of falls for the conditions of eyes opened and eyes closed on a firm surface (Merlo et al., 2012). Impaired balance in the lateral direction was related to a risk of falls (Tanaka et al., 1999), while the mediolateral displacement of the centre of pressure was associated with future falls (Piirtlola, 2006).

Tasks related to gait changes have been identified as fall predictors (Bridenbaugh & Kressig, 2011) among older adults with FOF without normal gait (Chamberlin, 2005). Gait speed is a simple and fast variable for measuring fall risk (Verghese et al., 2009) and functional capacity for health outcomes in community-dwelling older adults (Peel et al., 2013).

Primary outcomes included functional mobility (the Timed-Up-and-Go-TUG task), mobility as the functional reach test (FRT), fear of falling (the 16-item Falls Efficacy Scale-FES, questionnaire) and postural stability by force platform using COP displacement to evaluate the parameters in mediolateral (ML) and anteroposterior (AP) directions under both eyes open and closed conditions.

Secondary outcomes included falls in the past year (within 12 months), the number of falls recorded during the study, gait (the 10-minute walk test- 10MWT and the

six-minute walk test- 6MWT) and the Dynamic Gait Index (DGI). In case of incomplete or missing data for spatiotemporal parameters of gait for RCTs in healthy subjects.

2.2.6 Quality assessment

The risk of bias in assessing the quality of the included studies was evaluated by two independent reviewers (LD and CM). Consensus was reached at a later meeting between the two authors.

The inclusion criteria were evaluated using the Database of Physiotherapy Evidence (PEDro) scale (http://www.pedro.org.au/english/downloads/pedro-scale) for RCTs, which contained 10 questions to assess the study quality. A study score of 6 to 10 is considered moderate to high quality and a score less than five is considered lower quality according to their guidelines (http://www.pedro.org.au/english/downloads/pedro-statistics/). Consensus was reached by the two independent graders and there was no requirement for a third reviewer to resolve disagreements.

2.3 Data analysis

Statistical analyses were performed using the software package Statistic 10.0 and Cochrane Review Manager Software (RevMan 5.4, Cochrane Collaboration). A value of $\alpha = 0.05$ was considered statistically significant.

Data were entered in the software as mean and standard deviation (SD) and the total number of participants in each study allocated into groups. The authors considered whether the studies reported on whether or not intention- to- treat analysis was used.

Data reported as standard errors or confidence intervals (CIs) were converted to SD using https://training.cochrane.org/handbook/current/chapter-06#section-6-5-2. If the extracted data were incomplete, the author was contacted by email for more details.

Continuous data outcomes were reported as the mean difference (MD) were reported with 95% CIs. Postural stability included two subgroups to evaluate the estimating effects for the variables for mediolateral directions (MLEO; MLEC) and for anteroposterior directions (APEO; APEC). Assuming pooled effects, a fixed-effects model with heterogeneity $I^2 \leq 50\%$ and a random-effects model with $I^2 \geq 50\%$ were used. Forest plots presented the comparison between the Pilates intervention group and the control group with no exercise. The variables TUG and FRT were also analysed for Pilates vs. other exercise groups. Dichotomous data for the number of falls in participants during the previous year and the number of falls during the intervention were reported as exploratory due to the lower reporting of data during the intervention programme.

2.4 Results

2.4.1 Study selection

A total of 1,720 records were screened and 1,657 were excluded. A total of 63 studies were assessed for full-text eligibility and 51 were excluded. Twelve RCT studies were identified after the selection process for systematic review and meta-analysis; one study was excluded for the analysis as the authors included path length variable as opposed to ML and AP variables of balance (Donath et al., 2016) (see Fig.2 Studies included). The studies were conducted between 2012 and 2019.

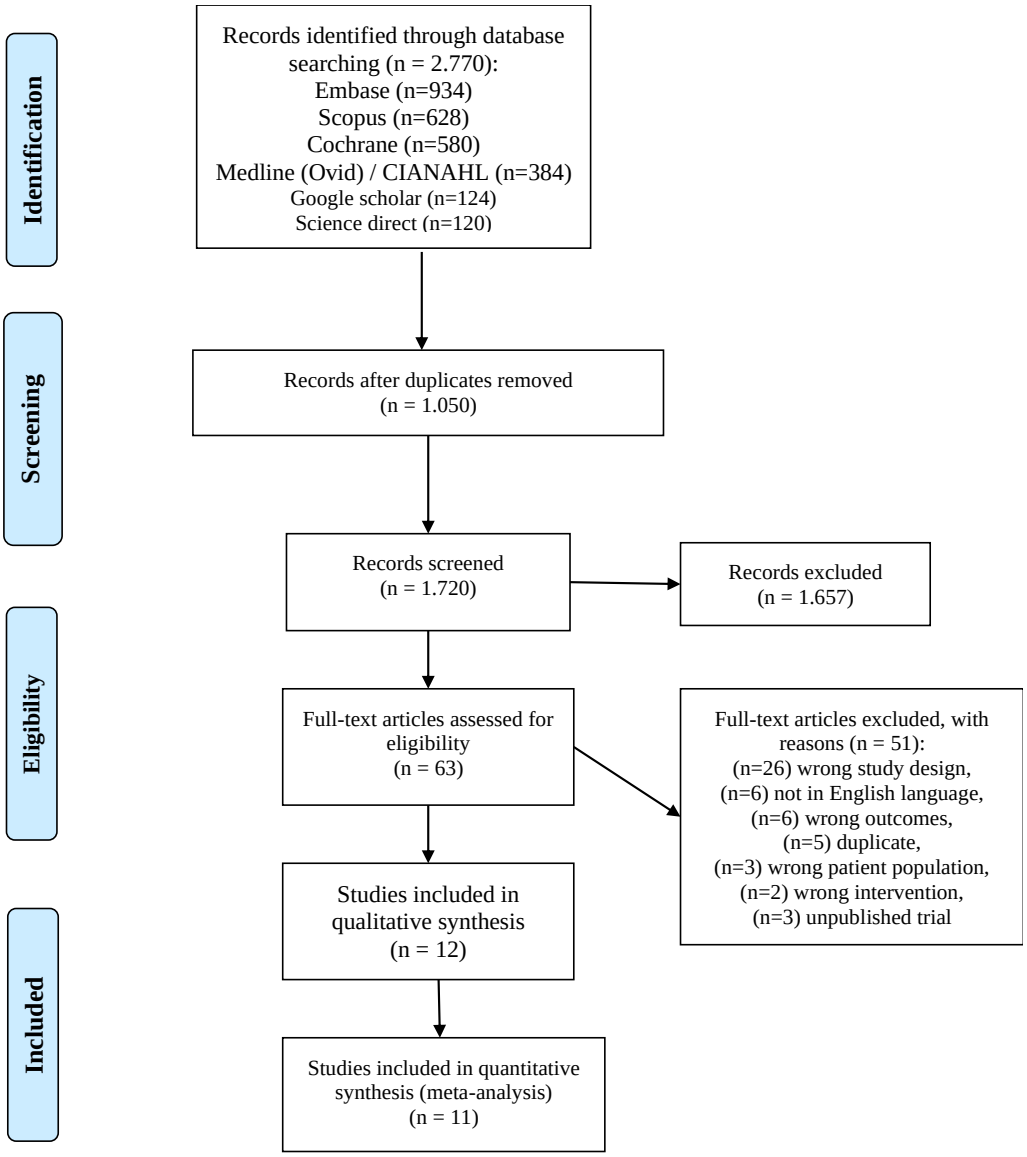

Figure 2 Studies included

2.4.2 Participants

In total, 702 participants were included, with 308 allocated to Pilates group (PG), 316 to Control group, (CG) and 78 to the three-arm exercise group.

Nine studies included both men and women (Bird et al., 2012; Surbala et al., 2014; Barker et al., 2016; Donath et al., 2016; Gabizon et al., 2016; Josephs et al., 2016;

Vieira et al., 2017; Badiei et al., 2017; Roller et al., 2018), while three (Mesquita et al., 2015; Oliveira et al., 2015; Aibar-Almazán et al., 2019) included only women.

Participants were healthy older adults, defined as older adults who have maintained functional ability (WHO). Six studies included healthy participants (Bird et al., 2012; Donath et al., 2016; Gabizon et al., 2016; Vieira et al., 2017; Badiei et al., 2017; Aibar-Almazán et al., 2019). Other studies have inclusion criteria with restrictions such as sedentary women (Mesquita et al, 2015; Oliveira et al., 2015) and fallers were included (Surbala et al.,2014; Barker et al., 2016; Josephs et al., 2016; Roller et al., 2018).

At baseline, six studies (Barker et al., 2016; Josephs et al., 2016; Gabizon et al., 2016; Badiei et al., 2017; Roller et al., 2018; Aibar-Almazán et al., 2019) reported participants who fell in the past year (n = 338 participants), shared between the Pilates group (n = 168) and control group (n = 170).

Five studies (Barker et al., 2016; Gabizon et al., 2016; Josephs et al., 2016; Badiei et al., 2017; Aibar-Almazán et al., 2019) reported the number of fallers (n = 283 participants) in the previous year at baseline before being allocated to the intervention programme. In the Pilates group (n = 141 participants), the number of fallers was 49 and in the control group (n = 142 participants), the number of fallers was 43. One study reported no events (falls) in the control group (Gabizon et al., 2016). Only two studies (Barker et al., 2016; Josephs et al., 2016) reported the number of falls during the intervention programme.

Two studies (Josephs et al., 2016; Roller et al., 2018) used TUG test scores ≥ 13.5s to screen participants with a history of falls. Josephs et al. (2016) also used Advanced Balance Scale (FAB) > 25 and Activities-Specific Balance Confidence

Scale (ABC). Surbala et al. (2014) used a FES-16 item score > 23 to screen participants.

The criteria for participants included a risk of sustaining a fall injury (Barker et al., 2016), having two or more falls or one injurious fall in the previous year (Roller et al., 2018), having at least one fall in the previous year (Surbala et al., 2014), having a fall in the past year or cut-off points for TUG or FAB, or able to complete the questionnaires without assistance (Joseph et al 2016).

2.4.3 Study characteristics

Of the twelve studies included in the systematic review, six compared Pilates intervention to a control group with no exercise (Bird et al., 2012; Barker et al., 2016; Vieira et al., 2017; Badiei et al., 2017; Roller et al., 2018; Aibar-Almazán et al., 2019). One crossover study (Bird et al., 2012) was included (See table 1: Study and Participants characteristics).

Five studies compared Pilates intervention to other interventions, such as static stretching (Oliveira et al., 2015) and traditional strength and balance (Josephs et al., 2016). Three three-arm studies were included to compare Pilates intervention to the following: conventional balance training and control (exercise) (Surbala et al., 2014); Pilates neuro-proprioceptive facilitation group (PNFG) and no intervention (daily activities) (Mesquita et al., 2015); and multimodal balance training and no intervention (daily activities) (Donath et al., 2016). One study aimed to prevent falls (Barker et al., 2016), one looked at alternatives to prevent falls (Mesquista et al., 2015) and one aimed to reduce falls (Josephs et al., 2016).

Table 1 Study and Participants characteristics

	Study and Participants characteristics					
Author/Year/ Country	*Design*	*Setting or Recruitment*	*Aims*	*Inclusion criteria*	*Total sample size (n), and between Intervention groups*	*Age: Mean (SD) between groups*
Aibar-Almazán et al, 2019 Spain	RCT	Community-dwelling postmenopausal women	To analyse the effects that an exercise programme based on the Pilates method would have on women aged 60 years and older concerning their postural control, FOF, and balance confidence when performing daily activities.	Women, aged 60 years and over and with at least 12 months since their final menstrual period, not involved in a Pilates exercise programme in the last year; and physically independent enough to perform basic daily activities (Barthel index-Mahoney & Barthel, 1965)	*Total, (n=110)* PILATES, PG *(n = 55)* / NO INTERVENTION, CG *(n = 55)*	PG = 69.98 (7.83) CG = 66.79 (10.14)
Barker et al, 2016 Australia	RCT	Advertisements in local general practitioner (GP), imaging and physiotherapy clinics; university newsletters; local community centers and newspapers.	To conduct a pilot, single blinded RCT to assess the feasibility of a Pilates exercise program that incorporates best practice guideline recommendations for falls prevention exercise and obtain a preliminary estimate of effect of the program on falls, fall injuries and fall risk factor outcomes to inform the design of a larger clinical trial.	Aged ⩾60 years; at risk of sustaining a fall injury based on a telephone screen developed by the research team (Box 1, available online); and able to negotiate a set of 10 stairs independently without a gait aid.	*Total, (n= 53)* PILATES PG *(n = 22)* / NO INTERVENTION CG, *(n = 31)*	PG = 69.25 (6.74) CG = 69.41 (5z.76)
Bird et al, 2012 Australia	RCT (crossover)	Local community groups in an urban area using radio and print media	To conduct a randomized controlled trial to investigate the effects of a Pilates intervention on the variables of static and dynamic balance and leg strength in a group of community-dwelling adults older than 60 years.	Participants did not currently have or had not recently had an acute medical condition. Volunteers who had controlled chronic conditions such as arthritis or stable chronic cardiovascular or metabolic conditions (eg, hypertension, diabetes mellitus) were included in the study.	*Total, (n=32)* PILATES, PG *(n==17)* / NO INTERVENTION, CG *(n=15),* at crossover PG *(n=14)* CG *(n= 13)*	No mentioned

					(daily activity monitored by (CHAMPS) questionnaire)	
Oliveira et al, 2015 Brazil	RCT	Community-dwelling older adults in the city of Jacarezinho State of Paraná, Brazil	To determine the isokinetic torque of the knee extensors and flexors, static and dynamic balance, functional mobility, and quality of life of community-dwelling older adults who performed a Pilates exercise protocol.	Age 60 to 65years; female; the ability to perform basic and instrumental activities of daily living without assistance; a body mass index (BMI) within the ideal range for the age group (22 to 27 kg/m2); a statement from a physician indicating sufficient fitness for the practice of physical exercises; not having practiced any type of physical exercise in the previous six months; and agreement not to participate in any other type of physical exercise during the study	*Total, (n=32)* PILATES, PG *(n=16)* / STATIC STRETCHING, CG *(n=16)*	PG = 63.6 (1.0) CG = 64.2 (0.8)
Donath et al, 2016 Switzerland	RCT 3 arms	Community-dwelling seniors	Investigating whether the neuromuscular training effects are in favour of a traditional balance training program (BAL) or a mat-based Pilates training (PIL) in a group of healthy community-dwelling seniors	Healthy seniors (75% women) without artificial joints, neurological and internal diseases, osteoporosis, acute and chronic back pain as well as trauma and balance or strength training experience within the last 6 months	*Total, (n=59)* PILATES, PG *(n=20)* / MULTIMODAL BALANCE TRAINING, BAL *(n=20)* / NO INTERVENTION, CG *(n=19)*. (daily activities)	PG =70.8 (6.5) BAL = 69.1 (5.8) CG = 69.2 (6.1)
Gabizon et al, 2016 Israel	RCT	Mail Community-dwelling, independent older adults were recruited from Lehavim, a community with a high social-economic ranking	To assess whether a Pilates-training program that includes classical Pilates exercises and exercises using Thera-Band elastic resistance bands and Swiss balls would improve balance control parameters associated with an increased risk of falling.	65 years of age or older, could ambulate independently (i.e., use of a cane was acceptable, but not a walker), did not have severe focal muscle weakness or visual impairment, did not have known neurological disorders (including stroke or Parkinson's disease), did not have metastatic cancer, and did not take medications that impair balance or strength. All subjects	*Total, (n= 88)* PILATES with balance, PG *(n = 44)* / NO INTERVENTION, CG *(n = 44)*	PG =70.3 (3.8) CG =72.1 (4.60

		near Beer-Sheva, in southern Israel		provided a medical waiver, signed by their primary care physician, clearing them to participate in moderate physical exercise.		
Josephs et al, 2016 USA	RCT	Local physicians in the area, seniors' groups at churches and community centers, word of mouth and notices posted in the local libraries	To investigate the effectiveness of Pilates group exercise versus traditional strength and balance group exercise for improving balance, reducing falls and improving balance confidence in community dwelling older adults with fall risk	65 years of age or older living in the community; impaired balance as defined by at least one of the following: a fall in the past year, TUG>13.5 s or FAB ≤ 25; and ability to follow instructions as assessed by the ability to complete the questionnaires without assistance. Subjects were not screened for ability, such as use of assistive device for walking, but only that they met the inclusion criteria of history of fall or meeting the cut off for balance compromise with the TUG or FAB.	*Total, (n=31)* PILATES / TRADITIONAL STRENGHT AND BALANCE No mentioned	PG = 75.6 (6.2) TG = 74.5(6.9)
Mesquita et al, 2015 Brazil	RCT 3 arms	Older women belonging to a church project	To conduct a randomized controlled trial to investigate and compare the effect of both exercise methods on the static and dynamic postural balance variables in elderly women, thus identifying alternatives to prevent falls and promoting functional independency	Women who were sedentary as evaluated using the International Physical Activity Questionnaire and aged 60 to 80 years were included in the sample	*Total, (n=63*) PILATES, PG *(n=21)* / PNFG (n=21) / NO INTERVENTION, CG (n=21) (daily activity)	PG = 67.3 (4.9) PNFG = 68.5 (5.4) CG = 71.5 (6.2)
Roller et al, 2018 California	RCT	Core Conditioning in Studio City advertisements in newspapers and at senior centers, and by word of mouth, and were screened via a telephone	To investigate whether Pilates Reformer exercises would improve balance, reduce fall risk, improve functional mobility, and improve balance confidence in adults age 65and older at risk for falls.	Aged 65 years or older, self-reported history of two or more falls or one injurious fall in the past year, TUG test score of 13.5 s suggesting risk for falling and physician approval to participate in the study.	*Total, (n=59)* PILATES, PG *(n=27)* / NO INTERVENTION, CG *(n=28)*	PG =78.52 (7.57) CG =76.68 (6.79)

Surbala et al, 2014 India	RCT 3 arms	Ambulatory geriatric subjects were recruited from four different old age homes (OAH) in Surendranagar area	The study aims in determining and comparing the effectiveness of PI and CBT specially designed for the elderly population in improving functional balance and QOL.	Age between 65 -74 years both males and females ; able to walk at least 30 feet with or without an assistive device; not participating in any sports or physical therapy sessions; willingness to do physical exercise thrice a week with regular attendance; have fallen at least once within previous year; fear of fall scoring >23 in 16 item falls efficacy scale international questionnaire; Mini-Mental Status Examination score of 24; and no affirmative responses to the PAR-Q instrument for inactive older adults	*Total, (n=51)* PILATES PG (n=17) / CONVENTIONAL BALANCE TRAINING, CBT *(n=17)* / CONTROL, CG *(n=17)*. (exercise)	PG = 70.7 (2.7) CBT =70.3 (2.9) CG = 69.35 (3.0)
Vieira et al, 2017 Brazil	RCT	Community dwelling seniors	To investigate the effects of a 12-week Pilates-inspired exercise program on functional performance among community-dwelling older women	Each subject had been instructed to avoid caffeinated and alcoholic beverages and to not perform moderate or heavy exercise the day before and the day of the application of the protocols. Before beginning the test, subjects were interviewed and examined to confirm their good health and whether they had a normal night's sleep	*Total, (n=52)* PILATES, PG *(n=26)* / NO INTERVENTION, CG *(n=26)* (daily activity)	PG = 66.0 (1.35) CG = 63.3 (0.91)
Badiei et al, 2017 Iran	RCT	Elderly women who were referred to the Day Care Center of Kahrizak Sanatorium (Alborz Province) via the convenient sampling method.	To determine the effect of Pilates exercise on Fear of Falling (FOF) among elderly women	Age between 60 to 80 years, willingness to join the study and signing the consent form, having medical approval that certifies the person's ability to participate in physical activity and exercise routines, no history of hospitalisation in the past 3 months as well as ability and availability to attend at least 80% of the Pilates exercise sessions.	*Total, (n=44)* PILATES, PG *(n=22)* /NO INTERVENTION, CG *(n=22)* (daily activity - (stretching training) as usual.	PG = 68(5.9) CG =71(4.1)

Abbreviations: Fear of falling (FOF), Randomised control trial (RCT), general practitioner (GP), Pilates group (PG), control group (CG), balance training program (BAL), mat-based Pilates training (PIL), Body Mass Index (BMI), Advanced Balance Scale (FAB), Time Up and Go (TUG), old age homes (OAH), Principal investigator (PI), Quality of life (QOL), Conventional Balance Training (CBT), Physical Activity Readiness Questionnaire (PAR-Q), Pilates neuro-proprioceptive facilitation group (PNFG) Advanced Balance Scale (FAB), Activities-Specific Balance Confidence Scale (ABC)

2.4.4 Risk of bias within studies

Of all the RCTs, only one achieved the highest quality score of 10 (Aibar-Almazán et al., 2019). Seven studies were of moderate to high quality scoring between 6 to 9 (Bird et al., 2012; Surbala et al., 2014; Mesquita et al., 2015; Oliveira et al., 2015; Barker et al., 2016; Donath et al., 2016; Gabizon et al., 2016); four studies scored lower (between 5-7) (Josephs et al., 2016; Vieira et al., 2017; Badiei et al., 2017; Roller et al., 2018) (table 3).

Five studies did not have concealed allocation (Mesquita et al., 2015; Donath et al., 2016; Josephs et al., 2016; Badiei et al., 2017; Roller et al., 2018). Three studies were not similar at the baseline (Gabizon et al., 2016; Joseph et al., 2016; Badiei et al., 2017). Only one study was blinded from subjects (Aibar-Almazán et al., 2019). Two studies were blinded from therapists (Donath et al., 2016; Aibar-Almazán et al., 2019). Four studies were unblinded to the assessors (Oliveira et al., 2015; Donath et al., 2016; Vieira et al., 2017; Badiei et al., 2017). Three studies did not have appropriate follow-up (Bird et al., 2012; Gabizon et al., 2016; Vieira et al., 2017). Seven studies used intention to treat analyses (Aibar-Almazán et al., 2019; Bird et al., 2012; Surbala et al., 2014; Oliveira et al., 2015; Barker et al., 2016; Badiei et al., 2017; Roller et al., 2018). Only one study did not compare between group analysis (Surbala et al., 2014) (see table 2: Quality of assessments of include studies).

Table 2 Quality of assessments of include studies

12 Studies	Random allocation	Concealed allocation	Similar at baseline	Blinding of subjects	Blinding of therapists	Blinding of assessors	Follow-up	Intention to treat analysis	Comparison between groups	Point measures variability	Score
Aibar-Almazán et al, 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10/10
Barker et al, 2016	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8/10
Bird et al, 2012	Y	Y	Y	N	N	Y	N	Y	Y	Y	7/10
Oliveira et al, 2015	Y	Y	Y	N	N	N	Y	Y	Y	Y	7/10
Donath et al, 2016	Y	N	Y	N	Y	N	Y	N	Y	Y	6/10
Gabizon et al, 2016	Y	Y	N	N	N	Y	N	N	Y	Y	6/10
Josephs et al, 2016	Y	N	N	N	N	Y	Y	N	Y	Y	5/10
Mesquita et al, 2015	Y	N	Y	N	N	Y	Y	N	Y	Y	6/10
Roller et al, 2018	Y	N	Y	N	N	Y	Y	Y	Y	Y	7/10
Surbala et al, 2014	Y	Y	Y	N	N	Y	Y	Y	N	Y	7/10
Vieira et al, 2017	Y	Y	Y	N	N	N	N	N	Y	Y	5/10
Badiei et al, 2017	Y	N	N	N	N	N	Y	Y	Y	Y	5/10

Abreviation: Y (Yes), N (No)

2.4.5 Interventions

This study focused on the PICOs method. The intervention included all types of Pilates methods, but the variables ‘intensity’, ‘dose’ and ‘type of Pilates method’ could not be considered in the meta-analysis. The strength of this study design is in its synthetisation of the results from the RCTs and the outcomes of fall risk factors. (*It is not always feasible to conduct randomised trials of all intervention types [e.g. the ‘structural’ interventions mentioned in Section 17.2.3]* [cited in Cochrane interventions handbook Section 17.2.5.)

2.4.5.1 Period of Pilates exercise

The Pilates intervention period was from four to twenty-four weeks. The twelve-week period was more common among the studies (Oliveira et al., 2015; Gabizon et al., 2016; Josephs et al., 2016; Vieira et al., 2017; Aibar-Almazán et al., 2019) (See table 3).

The following studies had different periods of interventions: four weeks (Mesquita et al. 2015); five weeks Bird et al. (2012); six weeks (Surbala et al., 2014); ten weeks (Donath et al., 2016; Badiei et al., 2017; Roller et al.,2018). The study by Barker et al. (2015) included three analyses at baseline, after 12 weeks and after 24 weeks; the 24-week period was the longest period that recorded falls.

2.4.5.2 Number of sessions

One to three Pilates sessions were held per week for 45–60 minutes each.

Eight studies (Bird et al., 2012; Surbala et al., 2014; Oliveira et al., 2015; Barker et al., 2016; Donath et al., 2016; Josephs et al., 2016; Vieira et al., 2017; Aibar-Almazán et al., 2019) included two sessions per week for 60 minutes each. Three studies (Gabizon et al., 2016; Mesquita et al., 2015; Badiei et al., 2017) included three sessions per week for 50 minutes each. Only one study included a single session per week lasting only 45 minutes (Roller et al., 2018).

2.4.5.3 Materials

Two studies included only mat Pilates (Donath et al., 2016; Badiei et al., 2017); Badiei et al. (2017) used the programme from Perez et al. (2014).

Six studies included mat Pilates with accessories (Surbala et al., 2014; Mesquita et al., 2015; Gabizon et al., 2016; Vieira et al., 2017; Aibar-Almazán et al., 2019); one was in the traditional group (Josephs et al., 2016). Three studies included the use of Pilates equipment (Oliveira et al., 2015; Roller et al., 2018; Josephs et al., 2016), while Josephs et al., had two Pilates groups (accessories vs equipment).

Three studies used a mix of Pilates techniques, including the mat with accessories, standing position (Bird et al., 2012; Surbala et al., 2014; Barker et al., 2016) and equipment (Bird et al., 2012; Barker et al., 2016).

Three studies included supplementary at-home exercises (Bird et al., 2012; Barker et al., 2016; Josephs et al., 2016). Barker et al. (2016) included educational materials for falls prevention and suggested that participants should exercise for twenty minutes on a daily basis. At-home Pilates exercises with mat were performed occasionally each week (Bird et al., 2012), participants performed the exercise for fifteen to twenty minutes on the day that there was no intervention program and after the program ended, participants continued to do the exercises for 8 weeks (Josephs et al., 2016).

Table 3 Pilates exercise intervention, Outcomes measures, results, participants analysed and recommendations

Pilates exercise intervention, Outcomes measures, results, participants analysed and recommendations				
Study	*Pilates Intervention*	*Outcome measures of interested AND Results*	*Participants (n) analysed Intention to treat (IT) by groups AND number of participants falls in the past year n (%) included in the study*	*Recommendations*
Aibar-Almazán et al, 2019 Spain	12 weeks / 2 sessions per week / 60 minutes The last sessions involved equipment such as resistance bands, rings, and balls.	International Falls Efficacy Scale- FES-16= Mean (23.77-24.80) = +1.03 Time, p= 0.023. Postural Stability: Mediolateral (X): eyes opened (EO) Mean (9.78-9.45) =-0.33. Eyes closed (EC) Mean (9.85-10.10) =0.25. Antero-posterior (Y): (EO) Mean (18.43-18.69) =-0.37 (EC) Mean (18.63-18.23) =-0.4	IT- yes PG = 55 CG = 52 Number of participants falls in the past year, *n (%)* Pilates, 25 (45.45%) Control, 17 (32.69%)	Future studies should consider the mid- and long-term effects, on both men and women, of the intervention here described.
Barker et al, 2016 Australia	24 weeks / 2 sessions per week / 60-minutes Pilates class practice guidelines for exercise to prevent falls (educational letter). Home exercises (20 min) >50 hours over total study period Standing exercises. Equipment: reformer, trapeze, Wunda chair, chi ball, elastic band and foam roller.	Functional reach test- FRT Pilates group Test 1=25.06 (4.88) test 2=31.78 (3.86) Test 3=31.40 (3.75) Control group Test 1=23.99 (6.02) Test 2=26.12 (4.48) Test 3=24.80 (5.09) Effects 24 weeks β (95% CI) 0.07 (0.00 to 0.14), P=0.046 Timed Up and Go- TUG Pilates group	IT- yes PG = 20 CG = 29, and CG = 24 (fall) Number of participants falls in the past year, *n (%)* Pilates, 6 (30%) Control, 9 (38%) Number of Falls Pilates, n =13 Control, n= 11	Pilates exercise is an enjoyable and acceptable form of exercise in community-dwelling older people at risk of falling. An appropriately designed Pilates exercise program appears to improve standing balance and reduce the risk of falls. Based on the fall injury rates estimated here, we can estimate (with 80% power) that a future definitive study would require 402 participants per arm to detect a 30% difference in fall injury rates. These estimations are based on a negative binomial distribution and a

		Test 1=10.99 (2.49) test 2=9.33 (2.09) Test 3=9.37 (2.05) Control group Test1=10.44 (2.47) Test 2=9.98 (2.50) Test 3=9.77 (2.37) Effects 24 weeks β (95% CI) −0.07 (–0.17 to 0.03), P= 0.161 Dynamic gait index -DGI Pilates group Test 1=19.70 (2.49) Test 2=21.50 (2.74) Test 3=21.55 (3.02) Control group Test 1=19.90 (2.78) Test 2=20.00 (3.20) Test 3= 20.62 (2.82) Effects 24 weeks β (95% CI) 0.05 (0.00 to 0.10), P=0.042 There were significant improvements (P< 0.05) in the intervention group compared with the control group for FRT, TUG and dynamic gait index. The majority of significant changes observed at 24 weeks for the Pilates group were also significant at 12 weeks, suggesting changes were achieved within 12weeks following the Pilates intervention and then maintained for a further 12 weeks of observation.		six-month follow-up period. A large RCT that includes around 804 people is warranted to confirm effects.

		There was no significant difference in the falls rate per 1000 person days across groups (incidence rate ratio=1.17, 95% CI (confidence interval) 0.43 to 3.16) The rate of fall injuries was 42% lower in the intervention group relative to the control group, and injurious falls 64% lower, but differences did not reach statistical significance (P=0.347; p= 0.136, respectively).		
Bird et al, 2012 Australia	5 weeks / 2 sessions per week / 60 minutes After a 6-week washout period, participants perform the alternate intervention. Classes consisted of standing exercises / Pilates reformer and mat-based exercises. Home-based with a diary	The Timed Up and Go - There was a significant improvement in results for the TUG Test (.90s faster) Postural Stability: Mediolateral sway on a foam cushion with eyes open (0.66cm less) and eyes closed (2.6cm less; all P= .016); with no significant improvement in the control group during this period For the pre- to post-control condition, there were no significant changes in any variables except mediolateral sway range with eyes open (firm surface; P=.047). The largest effect size was evident for the variable mediolateral sway range on the foam cushion with eyes closed for the Pilates condition (d.72).	IT- yes PG = 27 CG = 27	Although there were no between-condition differences between the Pilates and control conditions, significant improvements were observed in the pooled static and dynamic balance data from the 2 Pilates conditions. The reported improvements in mediolateral sway range and dynamic balance may have positive functional implications for physical fall risk factors in an older population.
Oliveira et al, 2015 Brazil	12 weeks / 2 sessions per week /60 minutes Equipment: combo chair, Cadillac trapeze table, universal Reformer and ladder barrel. All exercises were performed with one set of ten repetitions. The Borg CR10 scale21 was	The Timed Up and Go-TUG PG (7.7-5.7) = 2 CG (7.8-7.4) = 0.4	IT – yes PG = 16 CG = 16	Further studies are needed to determine the effects of Pilates for older adults. Based on the present findings, Pilates performed with equipment elicits improvements in lower limb muscle strength, static and

	used to determine the level of effort and load progression.			dynamic postural balance, functional mobility and quality of life of older adults when performed in two weekly sessions for 12 weeks.
Donath et al, 2016 Switzerland	8 weeks/ 2 sessions per week/ 60 minutes Mat Pilates 6 to 12 repetitions were performed during each exercise.	Postural Stability Different outcomes have been not including in analysis	No- IT PG = 17 BAL = 16 CG = 15	Pilate's training did not cause relevant adaptations. Future studies may also observe specific adaptations in neuromuscular, cognitive function and psychosocial health parameters could be assessed upon Pilate's training, e.g., in frailer and residential seniors. In these cases, randomized controlled 3armed study designs are recommended. Accordingly, any control condition should then consider appropriate group allocation and social gatherings, in order to avoid socially confounding situations.
Gabizon et al, 2016 Israel	12 weeks / 3 times a week / 60 minutes Classical Pilates method with Thera-Band elastic resistance bands and Swiss balls	Postural Stability Eyes closed: ML sway (mm) Intervention (42.42-37.65) Control (42-38.35) AP sway (mm) Intervention (37.83-34.64) Control (38.19-33.04) Eyes open: ML sway (mm) Intervention (27.10-25.8) Control (27.11-26.7) AP sway (mm) Intervention (28.18-25.8) Control (26.94-26.78)	No-IT PG = 44 CG = 44 Number of participants falls in the past year, *n (%)* Intervention 3 (6.8) Control 0 (0.0)	Further research should be conducted to assess the potential effect of Pilates training on a population of weaker older adults who have a history of falls.

Josephs et al, 2016 USA	12 weeks/ 2 times week / 60 minutes Pilates with Reformer, Cadillac and Chair apparatus. Each exercise 10 repetitions. The traditional group: elastic resistance bands, ankle weights, foam balance pads, boxes of varying heights and half foam rollers were props performed 20 repetitions. Home exercises 15-20 min. Monthly calendar to record their home exercise participation.	The Timed Up and Go-TUG (PG) 4.38-13.07=-1.31 (TG) 13.16-11.26=2.89	No- IT PG = 13 CG = 11 Number of participants falls in the past year: Pilates, n=10 Traditional, n=8 Number of falls Mean (SD) Pilates= 1.5 (1.3) ranged 0-4 Traditional=1.8 (2.2) ranged 0-7	Future research ideas include having 3 groups, Pilates, traditional and a control group and following the results longer term. This study indicates that balance and balance confidence can be improved in less than 50 h in patients with fall risk. A future research study should investigate this further in adults with fall risk.
Mesquita et al, 2015 Brazil	4 weeks / 3 times a week/ 50 minutes Mat Pilates, with Swiss ball, TheraBand, and magic circle.	Between groups comparison The Timed Up and Go-TUG (PG) −3.6 ± 2.3* (CG) 0.1 ± 3.7 (PNFG) −2.6 ± 1.3* P<0.001 Functional reach test -FRT (PG) 8.8 ± 5.0* (CG) 0.3 ± 7.9 (PNFG) 9.2 ± 4.8* P<0.001 Postural Stability Mediolateral: (PG) 7.2−2.4 ± 5.4 (CG) 0.6 ± 6.0 (PNFG) −4.2 ± P=0.069 Anteroposterior: (PG) 0.4 ± 4.0 (CG) 6 ± 5.5 (PNFG) −0.9 ± 5.2	No-IT PG = 20 CG = 18 PNFG = 20	Recommend that further studies include larger samples of elderly women and greater numbers of sessions. This will help to elucidate the optimal alternatives that can be applied to increase balance, allowing PNF and Pilates exercises to be used not only for rehabilitation, but also as a preventive method.

		P= 0.099		
Roller et al, 2018 California	10 weeks / Once a week / 45-minute Pilates with Reformer 10 repetitions each, using progressive resistance of 2 -4 springs Falls diary	The Timed Up and Go-TUG (PG) significantly decreased their TUG scores over time F (1,26) = 22.22, P<0.05, from 12.84 to 10.98 s. There was no significant change in TUG scores within the (CG) over time, P>0.05. 10 Minute walk test-10MWT (PG) significantly improved over time from 9.54 to 8.49 s (P<0.05) and the control group did not (8.51to 8.28 s), P>0.05. There were no significant between group differences on 10MWT scores (pre-intervention or post-intervention), P>0.05.	IT- yes PG = 27 CG = 28 Number of participants falls in the past year Mean (SD) Pilates= 2.00 (2.30) Control= 3.21 (5.57)	Future studies examining the effect of Pilates Reformer exercises on balance, gait, and fall risk in older adults may also want to consider performing exercises that work specifically on balance in upright postures such as standing on a moving carriage
Surbala et al, 2014 India	6 weeks / 2 times per week/ 45 minutes Mat Pilates, ball exercise and in standing position. All exercises were done for 10 repetitions with a rest period of two minutes before commencing the next exercise.	Functional reach test FRT (PG) 28.5±38.2 (CBT) 28.6±34.7 (CG) 29.4±29.6 The Timed Up and Go TUG (PG) 16.5±12.9 (CBT) 16.6±15.2 (CG) 16.6±16.1 Dynamic Gait Index-DGI (PG) 18.1±0.9 (CBT) 18.0±0.8 (CG) 17.9±0.9 P=0.759	IT- yes PG = 17 CBT = 17 CG = 17	Future research with cross over designs may also be conducted to determine the participants' preference of exercise program between PI and CBT. Further controlled comparative studies with larger sample size are recommended in community dwelling old elderly (over 75 years) individuals and those with pathological conditions (e.g. Stroke, Parkinsonism etc.) who are at higher risk of falls and falls related injuries

Vieira et al, 2017 Brazil	12 weeks / 2 times per week / 60 minutes Mat Pilates using accessories such as exercise rubber, bands, Swiss and exercise balls.	Timed Up and Go-TUG (14.6-0.6 s [95% CI 13.4 to 15.8] vs. 12.6-0.5 s [95%CI 11.6 to 13.5], p<0.02) 6-minute walk test-6 MWT increased the distance they walked in 6 min (510-9 m [95% CI 490 to 529] vs.542-11 m [95% CI 518 to 565], p<0.01).	No – IT PG = 21 CG = 19	Pilates-inspired exercises improved dynamic balance, lower-extremity strength, and cardiovascular fitness in community-dwelling older women. Therefore, it might be a potentially effective exercise regimen to maintain physical fitness and, possibly, to prevent disability and falls in old age. Yet, further investigation is needed to evaluate the effectiveness of the Pilates method on functional and physical fitness of older adults with characteristics that differ from those of our sample.
Badiei et al, 2017 Iran	8 weeks / 3 times per week / 60 minutes Mat Pilates by Perez et al. (2014)	Falls Efficacy Scale- FES-16 Significant difference after the completion of the Pilates exercise intervention (P<0.001) Mean difference between pre-test post-test scores in the control group was 33.7(4.2)-32.7(3.9)=1 score while the Pilates group 32.9(5.6)-22.18(2.8)= 10.72 scores, (P<0.001)	IT- yes PG = 22 CG = 22 Number of participants falls in the past year Mean (SD) Pilates= 1.54 (1.79) Control= 2 (2.4), p = 0.4 Pilates, *n (%)* YES 15(68.2) NO 5(22.7) Control, *n (%)* YES 17 (77.3) NO 7 (31.8), p = 0.5	The findings of the present study can help in creating a new attitude towards the possible roles of exercising in decreasing the risk of falling and other related factors in the elderly population, especially elderly women. In addition, health care providers can use this study to formulate similar interventional strategies that can improve the quality of life of the elderly.

2.5 Results

The outcomes are focused on reducing falls risk for the following outcome measures: mobility, functional mobility, fear of falling, gait and postural stability.

A total of 565 participants were included in the meta-analysis, with 282 allocated to PG and 283 to CG. A third exercise group included 37 participants.

2.5.1 Number of fallers participants

Only Josephs et al. (2016) (n = 31 participants) compared Pilates vs the traditional group (other exercise group), allocating n = 10 fallers to the Pilates group and n = 8 fallers to other exercise group.

Barker et al. (2016) was the only study to report the CI; no statistical significance was found—fallers n (%) = 7.5% (95% CI, –20.40 to 35.40, p = 0.601).

Roller et al. (2017) reported the number of fallers as mean (SD) = 2.00 (2.30) in the Pilates group and as mean (SD) = 3.21 (5.57) in the control group.

2.5.2 Number of falls during the intervention programme

Josephs et al. (2016) reported that the number of falls in the Pilates group was 0–4, with Mean (SD) = 1.5 (1.3). In the traditional group, the number of falls was 0–7, with mean (SD) = 1.8 (2.2) and p = 0.703; no statistical significance was found.

Barker et al. (2016) reported the total number of falls in the Pilates group (n = 13) and control group (n = 11) during the 24-week programme. This study was the only one to report the rate of falls per 1,000 person-days across groups, which was

calculated as the difference incidence rate ratio = 1.17 (95% CI, 0.43 to 3.16, p = 0.0754). They also stated that n = 2 falls (10%) occurred during the Pilates classes.

2.5.3 FES

Two studies (Badiei et al., 2017; Aibar-Almazán et al., 2019) included the Pilates group (n = 77) and the control group with no intervention (n = 74). The FES of a 16-item questionnaire on the fear of falling was used to analyses data (Badiei et al., 2017; Aibar-Almazán et al.,2019) (see figure 3: Forest plot – fear of falling).

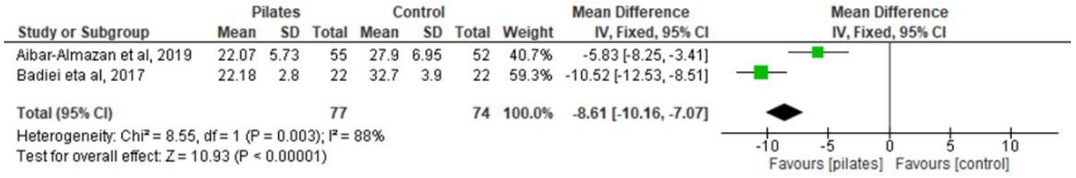

Figure 3– Fear of falling

The results show a decreased fear of falling score and statistically significant between groups in favour of the Pilates group: (MD = -8.61, 95% CI, -10.16 to -7.07, $p < 0.00001$, heterogeneity: $I^2 = 88\%$)

2.5.4 Postural Stability

Four studies (Bird et al., 2012; Mesquita et al., 2015; Gabizon et al., 2016; Aibar-Almazán et al., 2019) included two subgroups for mediolateral directions (MLEO; MLEC) (n=516) and two subgroups for anteroposterior directions (APEO; APEC) (n=408) in the meta-analysis. All participants (n = 924) were allocated to the Pilates (n = 450) and control (no intervention, n = 474) subgroups. The three-arm study (Pilates vs. other interventions) by Mesquita et al. (2015) was excluded. Other studies have not compared Pilates to other interventions.

Participants performed the balance test on a firm surface (platform) for 30 seconds in all the included studies. The studies included balance bipedal performance (Mesquita et al., 2015), quiet standing trials with eyes open and more than 10 seconds with eyes closed /blindfolded (Gabizon et al., 2016) and the Romberg test (Aibar-Almazán et al., 2019).

2.5.5 Mediolateral

Of the 516 participants included in this analysis, 264 were assigned to the Pilates group and 264 to the control group. The pooled overall balance improved, as seen in a decrease in scores after Pilates and was statistically significant between groups in favour of the Pilates group: (MD = -1.77, 95% CI, -2.84 to -0.70, p = 0.001, heterogeneity: I^2 = 3%)—the postural stability of the subjects increased (see figure 4: Forest plot – postural stability-ML).

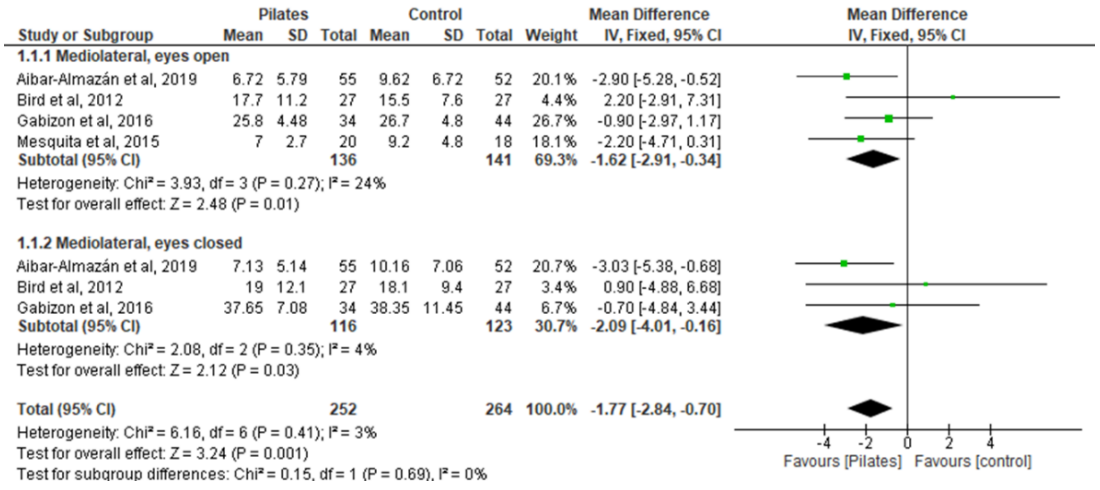

Figure 4 Postural stability-Mediolateral

The following four subgroups were shown separately on the forest plots:

MLEO: Four studies (Bird et al., 2012; Mesquita et al., 2015; Gabizon et al., 2016; Aibar-Almazán et al., 2019) included the Pilates group (n = 136) and the control

group with no intervention (n = 141). MLEO showed improvement in controlling postural stability with a decrease in the score and significant differences were found between the groups in favour of Pilates intervention: (MD = -1.62, 95% CI, -2.91 to -0.34, p = 0.01; heterogeneity: I^2 = 24%).

MLEC: Three studies (Bird et al., 2012; Gabizon et al., 2016; Aibar-Almazán et al., 2019) included the Pilates group (n = 116) vs. the control group with no intervention (n = 123). MLEC showed improvement in controlling postural stability with a decrease in the score and significant differences were found between the groups in favour of Pilates intervention:(MD = -2.09, 95% CI, -4.01 to -0.16, p = 0.03, heterogeneity: I^2 = 4%).

2.5.6 Anteroposterior

Of the 418 participants included in this study, 198 were assigned to the Pilates group and 210 to the control group.

The pooled overall balance had a decrease in scores after Pilates and no statistical significance between groups was found: (MD = -1.58, 95% CI, -3.74 to -0.59, p = 0.15, heterogeneity: I^2 = 51%) —the postural stability of the subjects increased (see figure 5: Forest plot – postural stability-AP).

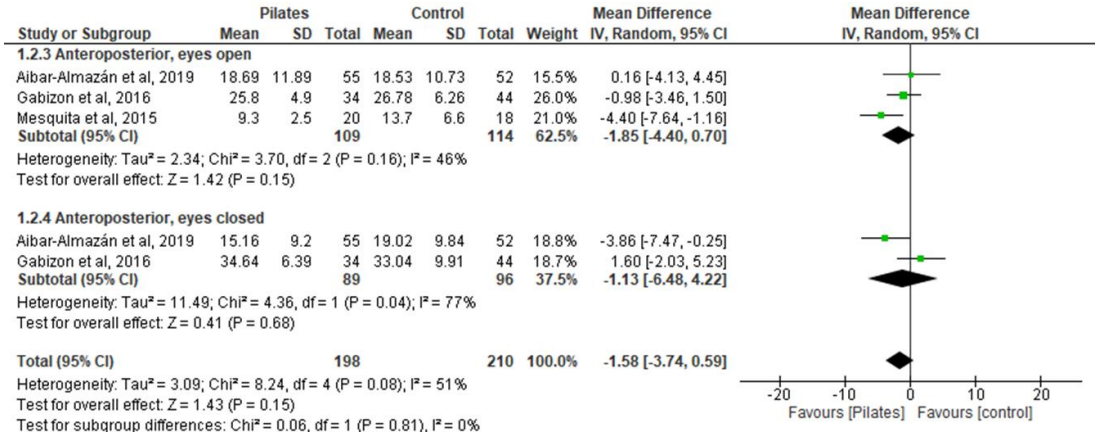

Figure 5 Postural stability-Anteroposterior

The following four subgroups were shown separately on the forest plots:

APEO: Three studies (Mesquita et al, 2015; Gabizon et al., 2016; Aibar-Almazán et al., 2019) included the Pilates group (n = 109) vs. the control group with no intervention (n = 114). No difference was found between the groups: (MD = -1.85, 95% CI, -4.40 to 0.70, p = 0.15, heterogeneity: I^2 = 46%).

APEC: Two studies (Gabizon et al., 2016; Aibar-Almazán et al., 2019) included the Pilates group (n = 89) vs. the control group with no intervention (n = 96). No difference was found between the groups: (MD = -1.13, 95% CI, -6.48 to 4.22, p = 0.68, heterogeneity: I^2 = 77%).

2.5.7 Gait

Two studies (Vieira et al., 2017; Roller et al., 2018) included exploratory results. Of the 95 participants included in this study, 48 were assigned to the Pilates group and 47 to the control group. Participants increase in the distance of (˜30 m, p < 0.01) the individual could walk in six minutes (6MWT) (Vieira et al., 2017) and the increase in velocity of (0.13 m/second) after Pilates measured by the ten-minute walking test (10MWT) (Roller et al., 2018). The (6 MWT) is a functional status and

common clinical test and it can be quickly and safely performed and measuring the exercise capacity, comorbidities, and endurance to older adults (Enright et al., 2003). The (10MWT) is a validated and reliable tool for measuring walking speed in adults (Bohannon, 1997). The MWT for both six and ten including a distance and time to walk test, however the tests were report by exploratory and no analysis has been done.

2.5.8 DGI

Two studies were included in this meta-analysis (Surbala et al., 2014; Barker et al., 2016), with a total of 37 participants in the Pilates group and 46 participants in the control group. (see figure 6: Forest plot – DGI).

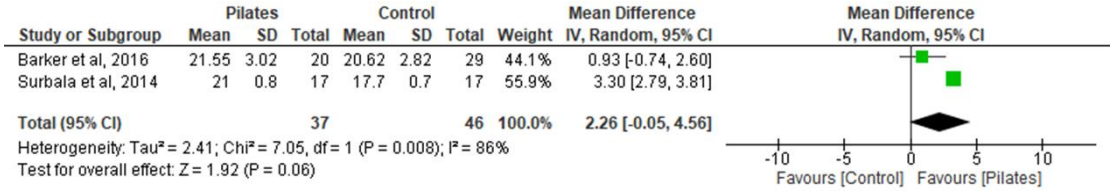

Figure 6 Dynamic Gait Index (DGI)

Participants showed an increase in their balance and gait scores with Pilates intervention; however, no significant difference was found between groups: (MD = 2.26, 95% CI, -0.05 to 4.56, p = 0.06, heterogeneity: I^2 = 86%).

2.5.9 TUG analysis for Pilates versus control groups

Five studies (Bird et al., 2012; Barker et al., 2016; Mesquita et al., 2015; Vieira et al., 2017; Roller et al., 2018) were included in the analysis, with a total of 115 participants in the Pilates group and 121 participants in the control group. (see figure 7: Forest plot – TUG1).

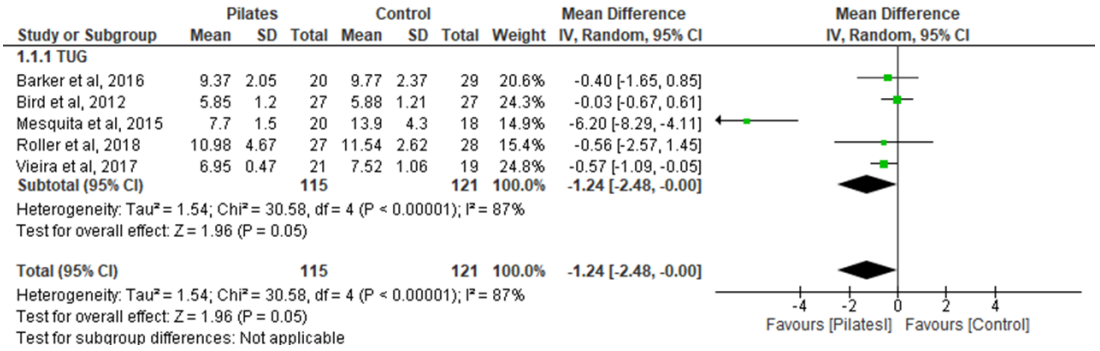

Figure 7 Time Up and Go (TUG1)

The results show no significant difference between the groups. There was a decrease in the time score (seconds) after Pilates intervention in favour of Pilates: (MD = -1.24, 95% CI, -2.48 to -0.00, p = 0.05, heterogeneity: I^2 = 87%).

2.5.10 TUG analysis for Pilates versus other exercise groups

Four studies (Oliveira et al., 2015; Josephs et al., 2016; Mesquita et al., 2015; Surbala et al., 2014) were included in the analysis with a total of 66 participants in the Pilates group and 64 participants in the control group. (see figure 8: Forest plot – TUG2).

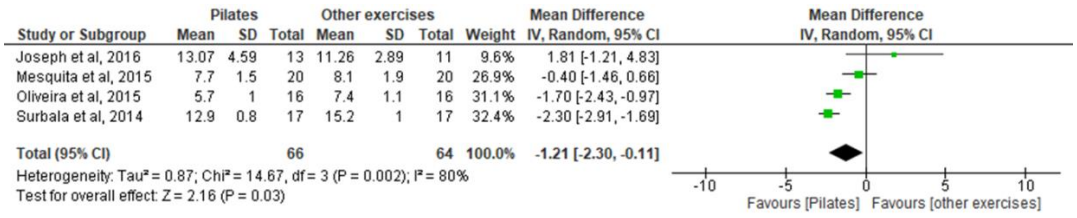

Figure 8 Time Up and Go (TUG2)

The results show a statistically significant difference between the groups and improvements in functional mobility in favour of the Pilates group by a decrease in the time score (seconds) after Pilates intervention: (MD= -1.21, 95% CI, -2.30 to -0.11, p = 0.03, heterogeneity: I^2 = 80%).

2.5.11 FRT analysed for Pilates versus control group

Three studies (Surbala et al., 2014; Mesquita et al., 2015; Barker et al., 2016) were included in the analysis, with a total of 57 participants in the Pilates group and 64 participants in the control group. (see figure 9: Forest plot – FRT1).

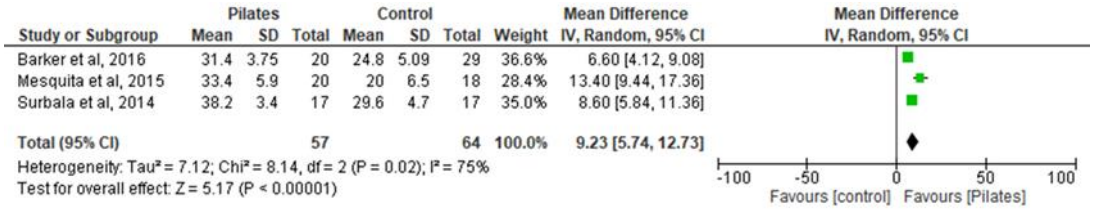

Figure 9 Functional Reach Test (FRT1)

There was a statistically significant difference between the groups and an increase in scores after Pilates intervention: (MD = 9.23, 95% CI, 5.74 to 12.73, $p < 0.00001$, heterogeneity: $I^2 = 75\%$).

2.5.12 FRT analysed for Pilates versus other exercise

Two studies (Surbala et al., 2014; Mesquita et al., 2015) were included in the analysis, with a total of 37 participants in the Pilates group and 37 participants in the control group. (see figure 10: Forest plot – FRT2).

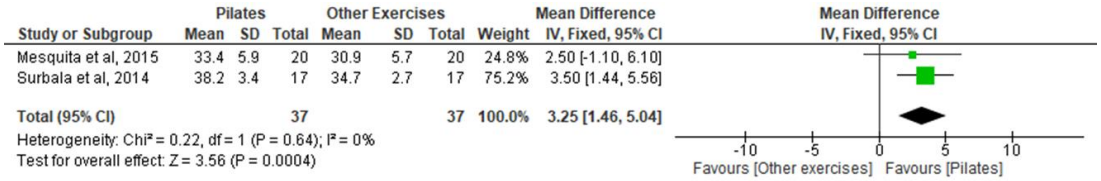

Figure 10 Functional Reach Test (FRT2)

There was a statistically significant difference between the groups and an improvement in the Pilates group, as evident from an increase in the score after

Pilates intervention (fixed-effects estimation): (MD = 3.25, 95% CI, 1.46 to 5.04, p < 0.0004, heterogeneity: I^2 = 0%). There was no evidence of heterogeneity.

2.6 Discussion

The aim of this systematic review and meta-analysis was to explore the effects of Pilates interventions on the following risk factors of falls; mobility, functional mobility, fear of falling, postural stability gait, and falls recorded during the Pilates intervention. To determine if Pilates interventions reduced the risk of falls in healthy older adults, who have maintained functional ability, including participants of both genders, those with a falls history, non-fallers, and individuals who were considered to be sedentary or active. All included studies were RCTs comparing Pilates intervention to control groups. However, only the TUG and FRT measures could be included in the model to compare Pilates to other exercises in the meta-analysis. The main findings of the review show that functional mobility, mobility, gait, postural balance and fear of falling have improved in older participants after practicing Pilates.

2.6.1 Functional Mobility and Mobility

Participants who undertook Pilates showed greater improvement in mobility/balance than functional mobility in healthy participants when comparing the Pilates group to the control group and to other form of exercises. With regard to FRT, no heterogeneity was found between the two studies presented (Surbala, 2014; Mesquita et al., 2015). There were similarities between the number of weeks of intervention (4–6) and in the use of mat Pilates with a ball. Pilates intervention showed sufficient effects to improve mobility/balance in older adults. Barker et al. (2015) included exercises involving the standing position with a narrow base, as the

standing balance stimulated the vestibular, visual and proprioceptive challenge. The Pilates intervention included a reformer, a trapeze, a Wunda chair, a ball, an elastic band and a foam roller for a 12-week programme with a practice guideline for falls prevention. In Surbala et al. (2014), the intervention included mat Pilates with a ball and compared to conventional balance training in fallers, was for a six-week period, with a frequency of twice per week and a duration of 45 minutes. In a study by Oliveira et al. (2015), Pilates improved functional mobility after two weekly sessions for 12 weeks and included the use of equipment. In the control group, the participants performed static stretching. The exercises in the mat Pilates intervention, which used accessories, were effective for that population. Mesquita et al. (2015) found a significant effect in both groups in terms of Pilates and proprioceptive and neuromuscular adaptations in the mat Pilates with accessories class after four weeks of intervention in sedentary women. Josephs et al. (2016) indicated better improvement in the traditional group (mat with accessories) than in the Pilates group that used equipment. In addition, participants performed home-based exercises after the 12-week programme.

With regard to TUG participants' functional mobility did not improve when compared to the control group. This may be due to the heterogeneity of the methods in the studies, which included both healthy participants and participants with a previous history of falls. Vieira et al. (2017) included active participants who might not have had improvement in functional mobility, while Roller et al. (2018) included participants with the risk of falls and had not shown much improvement as well.

2.6.2 Balance Test

In this meta-analysis, Pilates had a positive effect on postural balance in healthy individuals. Considering the mediolateral variable under eyes-open and eyes-closed conditions, there were statistically significant differences between the Pilates and control groups, indicating that Pilates has positive effects and reduces the risk of falls. In a RCT crossover study, Bird et al. (2012) also reported a significant improvement in the mediolateral direction under eyes-closed conditions on foam, rather than on a firm surface; however, there was no statistical difference between the groups. It must be emphasised, however, that the washout period of six weeks was insufficient to remove the effects of Pilates and after this period, the participants showed neuromuscular adaptation. In contrast, Donath et al. (2016) found no significant results among their participants after Pilates training. However, their suggestions for future studies include adaptations in neuromuscular capability, cognitive function and psychosocial health and the use of a three-armed study design. Barker et al. (2015) concluded that the control group may have had ceiling effects and a third arm would avoid the effects of Pilates intervention and benefit falls prevention exercises. Furthermore, Gabizon et al. (2016) showed no improvement in postural stability after 12 weeks of training. This may be due to the Pilates protocol used, which did not include balance exercises for healthy participants. However, their exercises comprised three levels: 1- traditional Pilates with accessories, 2- Pilates with a Swiss ball and 3- Pilates involving sitting on a ball using a Theraband (Gabizon et al., 2016).

In this systematic review, postural balance outcomes were evaluated by only comparing the Pilates group to the control group. The quality of the included studies was medium to high on the PEDro scale. Overall, as well as considering the

subgroups, the variables analysed separately for mediolateral directions demonstrated good improvement and good homogeneity and the anteroposterior directions of balance showed heterogeneity. The APEC results should be interpreted with caution because only two studies were included in the meta-analysis for this variable. Further, a random effect estimating for overall for the anteroposterior subgroup was applied due to no homogeneous studies included; however, the forest plot showed a similar weight between them (Gabizon et al., 2016; Aibar-Almazán et al., 2019). Aibar-Almazan and colleagues' study had shown great improvement in the decrease score for balance and it was the only study included in this review that was graded at the highest quality. The intervention was a 12-week period of Pilates undertaken twice a week and the authors found improvement in balance confidence, the fear of falling and postural stability; however, the authors stated that the best improvement was achieved with variables such as velocity of the COP with eyes open and APEC (Aibar-Almazán et al., 2019).

Mesquita et al. (2015) was deemed to be a medium-quality study. It did not include the intention to treat analysis and allocation was not concealed. Moreover, unblinded assessors and therapists were employed in the study. The intervention period was four weeks. The authors found improvement in postural static and functional test performance in both groups of Pilates and neuromuscular facilitation. However, there was no significant difference between the groups (Mesquita et al., 2015). It needs to be considered that the consequences of ageing affect muscle strength, proprioception, vision and balance of the standing body. Thus, there is a high dependence on the vestibular afferents due to small changes in the body when getting older (Pirker and Katzenschlager, 2017).

In the present study, the balance parameters in the anteroposterior direction under both conditions with eyes opened and eyes closed showed no significant difference between the groups. In another recent meta-analysis, different variables were included to analyse postural balance. Casonatto et al. (2020) included six studies in their meta-analysis. Participants performed the balance test on a force platform, with COP directions of ML and AP, area and velocity in the same analysis. Overall, the authors determined SMD to be 0.89 (0.29–1.49) and concluded that the effects of duration and quantity of intervention per week, as well as the quality of the intervention studies, are unrelated to the effects of postural balance.

de Souza et al. (2018), another Pilates meta-analysis, also used SMD and included two studies for the total sway area (force platform) and another task—one-leg standing. There was no statistically significant difference between the intervention groups. Low et al. (2017) warned that the results of postural control studies can be misinterpreted because the variables are not always analysed separately or the model employed does not use SMD.

2.6.3 Gait

In Roller et al. (2018), healthy participants improved and increased their gait speed after a Pilates intervention using reformer equipment after four weeks of once a week intervention to decrease the risk of falls; however, participants who had more functionality had greater improvements in static and dynamic balance. Improved speed was related to increased strength. The study included the 10MWT test using a timed test to measure participants' speed (Bohannon et al., 1996). It was noted that there was an improvement in gait speed. According to Verghese et al. (2009), if

each participant walked 10 cm/sec, a reduced gait speed is associated with a 7% increase in the risk of falls

A Pilates study found that participants improved their aerobic capacity and functional exercise by increasing the distance of a 6MWT after 12 weeks of mat Pilates with accessories such as rubber bands and Swiss balls; however, lower-limb strength could influence the performance test, as the participants were active (Vieira et al., 2017). The study was considered of a lower quality and was unblinded. Moreover, the follow up was inadequate and there was no intention to treat analysis. de Souza et al. (2018) evaluated participants after 12 and 24 weeks of intervention and found statistically significant differences between the groups for a 6MWT (SMD = 2.00, 95% CI 1.44–2.56).

2.6.4 Fear of falling and falls

Participants decreased their concern about falling while doing activities through Pilates intervention compared to control groups. Two studies (Badiei et al., 2017; Aibar-Almazán et al., 2019) included healthy older women. Kumar et al. (2014). If fear of falling affects an individual's health and social activities, they will experience a decrease in physical abilities and reduce their daily living activities. However, in Badiei et al. (2017), the mat Pilates exercises ran for eight weeks, three times a week. The study included women who were sedentary due to their sociocultural conditions and limited the women to practised exercises. In Aibar-Almazán et al. (2019), the Pilates exercise ran for 12 weeks, twice weekly and used accessories such as resistance bands, rings and balls. The study was considered to be of a high quality, was blinded, had included intention to treat analyses and had a sample size greater than the other studies.

Fear of falling is more apparent among individuals who have experienced previous falls and there is an association with reduced gait speed, stride length, double support time (Maki, 1997; Reelick et al., 2009).

In the present study, there was a lack of data for fallers and no fallers, these dichotomous variables were not analysed for the risk of falls; there were only two studies that included the number of falls that occurred during this period—Barker et al. (2016) evaluated the risk factors, which included falls and injuries; however, the results showed that there was no significant difference between the Pilates and control groups for the rate of falls. Barker et al. (2016) and Josephs et al. (2016) showed that there was a reduction in scores, favouring the Pilates group. Four studies (Gabizon et al., 2016; Badiei et al., 2017; Roller et al. 2018; Aibar-Almazán et al., 2019) did not include data on the number of falls occurring during their intervention programme. Roller et al. (2018) reported that the number of falls during the intervention programme was missing.

2.6.5 Studies' recommendations for fall prevention

Barker et al. (2016) recommended specific training with a physical therapist, including exercises in a standing position, to reduce the risk of falls. Bird et al. (2012) noted an improvement in the mediolateral directions of balance and participants' dynamic balance showed the intervention's positive implications for physical fall risk factors in older adults. Roller et al. (2018) noted that more studies are needed to assess the effects of Pilates using Reformer equipment as related to balance, gait and falls risk in older adults. Further specific exercises focused on balance in upright postures for standing, moving and carriage were advised.

2.7 Limitations of the Review

This systematic review and meta-analysis have some limitations. The study included only RCTs, full-text versions and articles published in English. However, the study included studies that ranged in quality from medium to high. It was not possible in this study to analyse Pilates interventions in comparison to other exercise groups in terms of the most selected measures, and not all studies included focused on falls. Some low-quality studies included other forms of exercise, and the studies included focused on the outcome measures to decrease falls risk, where the primary outcomes of this study were functional mobility and postural balance.

There is still insufficient evidence in the literature to state conclusively that Pilates is an effective form of exercise to prevent falls. Concerning the number of falls and the number of fallers reported during the intervention programme, there were other limitations related to the low number of studies included. Moreover, meta-analyses are also dependent on heterogeneity among studies, such as in the clinical implications, Pilates methods and test measures used. However, according to Casonatto et al. (2020), the heterogeneity of Pilates intervention methods (frequency, duration and quality of studies) previously mentioned was unrelated to the effects on postural balance. This study followed the PICO criteria to focus on measures to decrease fall risk. In addition, due to the lower number of RCTs in Pilates, it was preferred to include all types of Pilates interventions.

There was no improvement in dynamic gait index and it was not possible to analyse the spatiotemporal parameters of gait due to the lack of research data in this area. Thus, the spatiotemporal parameters of gait were lacking in the RCT Pilates studies. Most RCT Pilates studies that have analysed gait parameters have considered neurological participants for the inclusion criteria. Further, Pilates studies that have included gait parameters did not have groups comparison for healthy participants.

With these gaps this study did not include the spatiotemporal parameters of gait outcomes. However, the clinical assessments (MWT) for gait were included. Moreover, it was not possible to analyse gait due to the lower number of studies included.

2.8 Future research

This systematic review and meta-analysis included only RCTs, meaning the quality and rigor of the methodology were increased. Further outcomes and more evidence from RCTs must be provided. Future studies should consider the number of falls and of faller participants among their primary outcomes during the intervention programme. In addition, studies should include a diary of falls for everyone or an electronic app to monitor the daily falls of each participant. Future studies should investigate any benefits in saving cost as transportation, training Pilates instructor, exercises protocol of groups and classes with a supplementary home-based Pilates intervention or an individual home-based exercise. The risk of bias may increase; however, it is difficult to blind the participants and the instructor. Studies with a longer follow-up period are warranted.

2.9 Conclusion

There is some evidence to suggest that Pilates reduces certain risk factors for falls in healthy older adults. Pilates intervention, when compared to control groups, was shown to improve functional mobility, general mobility, postural balance, gait and fear of falling of healthy older adults, which may decrease their risk of falls. Pilates intervention, when compared to control groups, showed no improvement in functional mobility than other exercises. Pilates did, however, show greater

improvement in mobility than other exercises. It is evident that 4-6 weeks of Pilates intervention without equipment had positive results on general mobility. Pilates was found to improve fear of falling and postural stability in the mid-lateral directions with eyes open and closed, thereby potentially decreasing the risk of falls. Other evidence has shown conflicting results with regard to balance and postural stability including different measures. Further robust studies are needed to evaluate the number of falls and to incorporate participants with a falls history into a Pilates intervention programme with longer follow-up. The intervention programme, including different methods, has implications for future research with regard to the use of mat Pilates, equipment and the number of weeks required for the Pilates intervention.

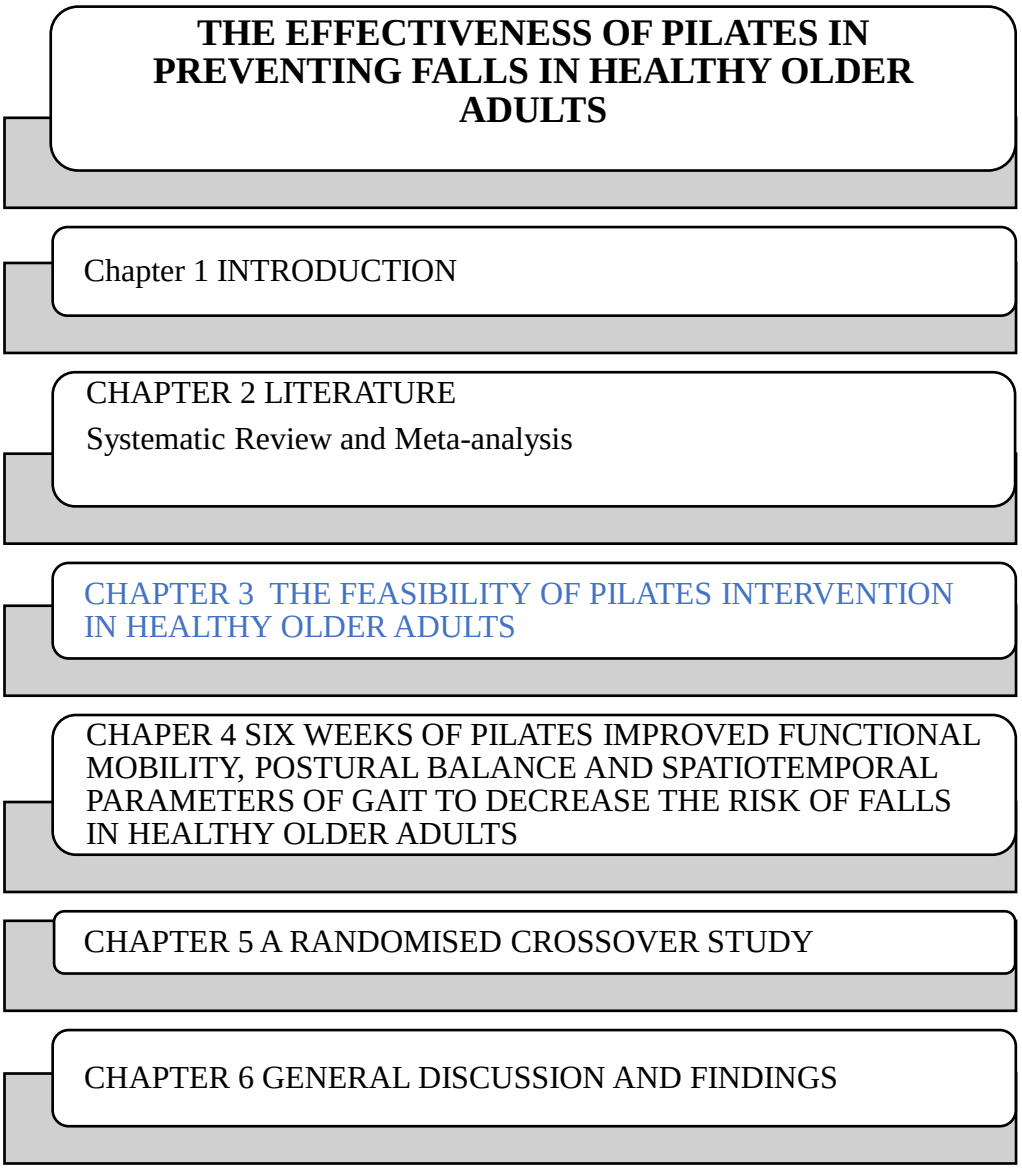

Figure 11 Layout of the thesis

CHAPTER 3 THE FEASIBILITY OF PILATES INTERVENTION IN HEALTHY OLDER ADULTS

This chapter presents the first study of the thesis. This feasibility study aimed to trial the instruments of a traditional Pilates intervention, with a six-week supplementary home programme in healthy older adults to reduce the risk of falls as determined by specific outcome measures such as functional mobility, mobility, fear of falling, physical activity, balance and spatiotemporal parameters of gait.

3.1 Research questions

- Is the proposed research design feasible?
- Do the measures and the six weeks of Pilates intervention protocol need to be modified prior to the next phase of the research?

3.2 Objectives

- Evaluate and refine variables and outcome measures;
- Introduce and evaluate the six-week Pilates intervention;
- Personalise, implement and manage the traditional Pilates intervention for older adults in Galway;
- Identify challenges and revise the exercises for older adults.

3.3 Hypothesis

A traditional Pilates training programme was used in the feasibility study to determine whether there would be value in progressing to an effectiveness study. Moreover, this was done to assess the practicality of the proposed research and identify any limitations or changes required to inform the cohort study.

3.4 Methodology

3.4.1 Ethical Approval

All participants signed an informed consent form before study commencement (Appendix 1). They were informed that they could withdraw from the study any time. The study was approved by the NUI Galway Research Ethics Committee (REC)-NUI Galway Ref 15/May/02 (Appendix 2).

3.4.2 Study Design

A non-experimental pre-test and post-test study design was used for this feasibility study. Participants completed the pre-test one week before starting the Pilates exercises and the post-test was completed one week after completing the six-week programme. This study presents the preliminary evaluation of the outcome measures, variables selected, refinement of gait variables, involvement and how the older adults will respond to the Pilates exercises.

3.4.3 Recruitment

Recruitment began in January 2016. The study was advertised on the Internet, in local newspapers and on the radio. The study information was also disseminated in retirement communities in Renmore, city centre, Newcastle and Salthill in Galway. The principal investigator held meetings with those interested in participating at the National University of Ireland Galway (NUI Galway).

i) The recruitment of participants was primarily undertaken in Galway retirement communities; the principal investigator (PI) (the PhD student) first contacted the coordinator of each group by phone to arrange an information meeting. In the first meeting, the PI had ten

minutes to give a general talk about the project. At the meeting, the PI explained the participation criteria, considerations for the screening test, assessments, class attendance and that parking at NUI Galway was provided.

ii) Further information leaflets were given to the volunteers interested in participating in the study and they were invited to contact the PI to attend the meeting at NUI Galway (Appendix 3).

iii) Posters were left at the post office in the city centre. The marketing office in NUI Galway also disseminated the study by email, newspaper and the internet. The study was announced on local radio in Galway City, Galway Bay FM, through an interview with the PI.

iv) Further emails were sent to groups, such as members retired from NUI Galway, Friends of the Elderly, the Lions Club group in Newcastle and Parkmore. Volunteers were also invited to share the details of the study with others who they thought they might be interested in participating in the study. Anybody who expressed an interest was advised to contact the PI to arrange an initial meeting.

One hundred individuals contacted the PI by either e-mail or phone. The Pilates intervention began in February 2016. After the study commenced, snowball sampling was employed to maximise the recruitment of additional individuals interested in participating in study two. The PI added these individuals to a waiting list to screen them for the subsequent cohort study, however, not all the individuals were interested in attending the next meeting. There were (n=42) eligible in the second study (See on the next chapter- 4).

This study, twelve individuals (n = 12) were eligible in participating in study 1. These individuals attended a meeting and signed a consent form.

The study's sample size was based upon the sample sizes employed in previous Pilates studies: n = 9 (Newell, 2012), n = 7 (Kaesler et al., 2007) and n = 18 (Bertoli, 2017).

3.4.4 Participants

Inclusion criteria for the study included healthy older adults who were able to attend the Pilates sessions frequently, had not had surgery in the past six months, had no restriction recommended by their General Practitioner and had a Montreal Cognitive Assessment (MoCA) score of over 26 (Nasreddine et al., 2005) (Appendix 6). Those excluded had a MoCA score of less than 26, had experienced a fall in the last six months, had acute or chronic musculoskeletal pain, for instance, chronic back pain, (Barker et al., 2016) and/or acute inflammation (injury: knee, hip, shoulder, i.e., tendinitis) and/or illness: i.e., unstable blood pressure, myocardial infarction or any disease that could limit the ability to perform exercise safely (Barker et al., 2016), had a history of neurological impairment, had medical and pharmacologic contraindications to exercise, vertigo or had a vigorous exercise routine already.

Of the 12 participants assessed for eligibility, three have not met the inclusion criteria because of their cognitive ability (n = 2) and unhealth (n = 1). Participants (n=3) were excluded due to lack of time (n= 1) and could not be included because they provided incorrect contact details (n= 2). In total, six participants were allocated to the Pilates intervention (See Figure 12- The modified CONSORT diagram of participants).

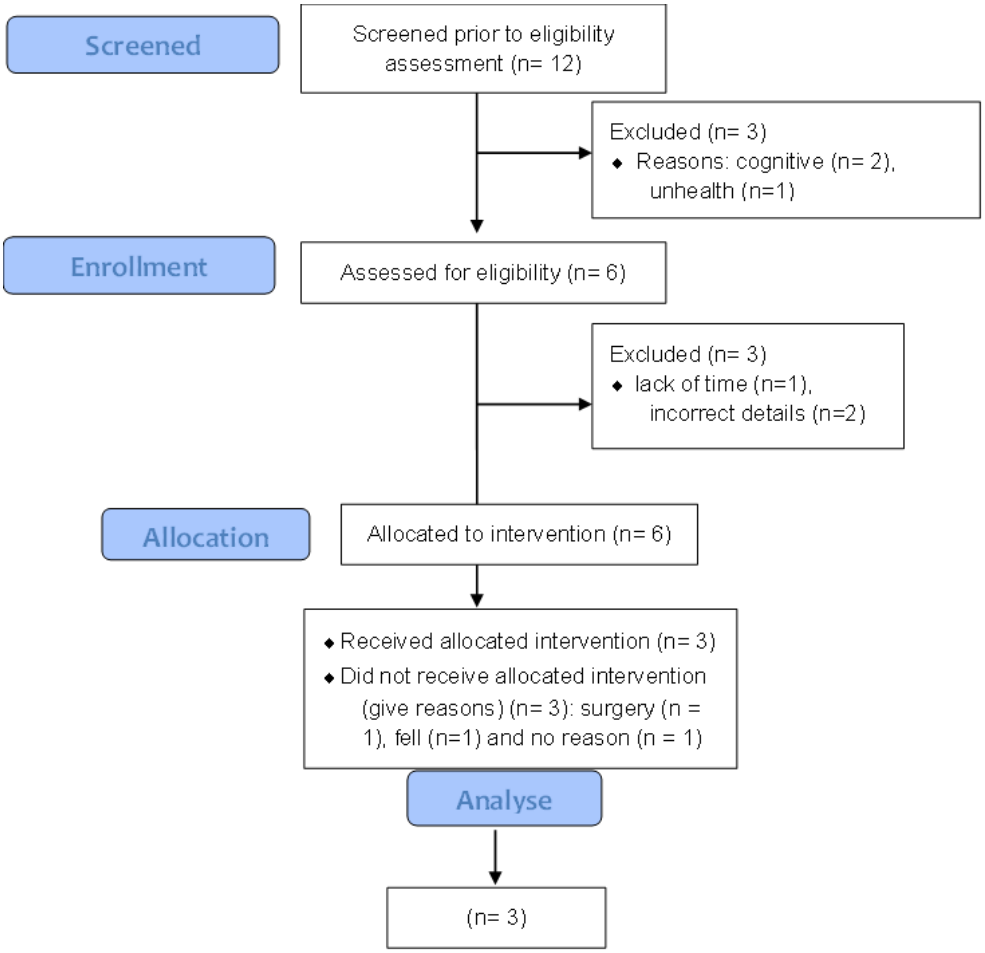

Figure 12 The modified CONSORT diagram of participants

3.4.5 Pilates Intervention

The personalised exercise programme was developed by selecting the original and traditional Pilates exercise from the creator, Joseph Hubertus Pilates (1920) for both supervised and home-based exercises. The exercises focused on the lower limb, core and trunk.

In class, the PI demonstrated each exercise and explained the exercises to the participants. The PI then demonstrated to the participants how to perform the breathing work during the exercise. The PI carefully watched how participants

executed the exercises and corrected and asked them to pay more attention to their key body points—arms, hip, neck, shoulders and spine when necessary.

The PI also demonstrated the home-based exercises to all the participants in the first supervised class. Participants received a booklet containing information about the home exercises. The last page of the booklet contained a sheet for them to write down their exercise notes every week and whether they had a fall during the programme. Participants were asked to make notes about which types of exercises they found to be the easiest or more difficult to perform during the intervention of exercises in class and at home. Participants were asked to give the sheet of notes to the PI on the day of the post-test (Appendix 12).

3.4.5.1 Frequency

The six participants were allocated to two small groups comprising three participants each for the Pilates intervention (groups 1 and 2). Pilates sessions were conducted twice weekly for 12 sessions. All the participants were asked to undertake the home-based exercises three times a week for six weeks.

3.4.5.2 Time

Each session of supervised Pilates was one hour in duration, which included warm-up, mat Pilates and cool-down exercises.

Home-based participants were asked to exercise for thirty minutes per session (See fig. 13 below)

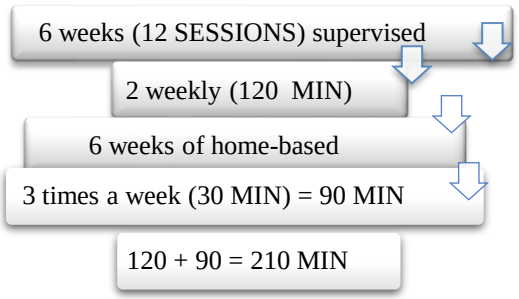

Figure 13 Timetable of Pilates intervention of six weeks

Exercises for fall prevention and physical functional fitness are recommended for older adults; exercises should be performed two or three days per week for twenty or thirty minutes per day and include motor skills for balance, agility, coordination and gait (Garber et al., 2011). The Physical Activity Guidelines Advisory Committee Report (2008) recommends that people aged 65 years and older should perform moderate intensity aerobic, muscle strengthening and balance activities for thirty minutes a day, five days per week, or at least one hundred and fifty minutes per week. A systematic review of Pilates suggested older adults should participate in a Pilates class lasting at least 60 minutes three times a week for six to ten weeks, or twice a week for four to ten weeks (Moreno-Segura, 2018).

3.4.5.3 Type of Exercise

Traditional mat Pilates without accessories.

3.4.5.4 Intensity

In the beginning, participants performed the basic level of Pilates exercise. The instructor evaluated their exercise progress every two weeks. After the third week, some intermediate-level exercises were added. The exercises were started with two sets of ten repetitions each, which was increased to three repetitions and maintained for six weeks.

3.4.5.5 Pilates Exercise Programme in class

Typically, eleven exercises are performed for stretching the muscles at the beginning and end of a Pilates session. However, to maintain the combined time of warm-up and cool-down at ten minutes, the exercises were separated. Exercise protocols were based upon previous Pilates studies (Pata et al., 2014; Hyun et al., 2014). The warm-up exercises included rolling the trunk down, rolling the shoulders, stretching the arms to the right and left, stretching the neck to the right and left, stretching individual legs and swaying the knees. The cool-down exercises included rolling the hip, straight leg hamstring lateral cross, rocking with the arms supporting the body, side lung abductor, stretching the calf and rolling the trunk.

Exercises were performed in standing, sitting and lying down positions. Standing exercises were pumping calf without hand support, aiming to stimulate the multisensory function (Barker et al., 2016). (Barker et al. 2015). The sitting position exercises aimed at improving postural control and the lying-down exercises focused on isometric, concentric and eccentric muscle contractions to exercise lower and upper limbs, lower back and abdominals (Gabizon et al. 2016).

In the first week participants performed the pumping calf with hands support and the second and subsequent week without hands support.

At the third week, intermediate level exercises were introduced: the hundred, spine curl and leg stretching exercises. These exercises progressed to level II and III. Participants performed the hundred exercise as self-position with their head down and bench knee up. The participants performed these exercises during the breath (inhale + exhale = five moves) and moved their arms five times up and down. The speed of breathing changed for some exercises; for example, in ‘the hundred’, the

practitioners might breathe in and out quickly while they are moving their arms up and down in short movements.

The intensity was increased in three exercises, as following the single-leg to lateral was one set for 30 seconds and the hip roll and straight-leg hamstring were sets of three for 30 seconds.

During weeks five and six, the scissors exercise was included. Participants increased their repetition for the saw and single leg stretch exercises of three sets with 10 repetitions. Participants maintained the bridge exercise for five seconds. For the hundred exercise, participants progressed to double leg up straight.

The exercises in the first class followed the following routine: 8 warm-up, 12 basic, 2 intermediate and 5 cool-down. The last class followed the following routine: 5 warm-up, 7 basic, 9 intermediate and 7 cool-down. All the exercises for the feasibility study were revised and they were established for the subsequent studies (see table 4).

Table 4 Pilates exercises

warm up **SUPERVISED PILATES**	
1. Rolling trunk 2 × 2. Shoulders rolling backward and forward 5 × 3. Stretching arm/neck 1 × 30 sec 4. Single leg stretches 3 × 30 sec 5. Knee Sway 3 × 30 sec	
1-3 week *Standing position*	**5-6 week** *Standing position*
1. Pumping calf 2 × 10 2. Squat 2 × 5 *Lying on the mat* 3. Shoulders drops 3 × 10 4. Breathing (arms up and down) 3 × 10 5. Table top- Maintain double legs up flex and move arms up and down 2 × 10 6. The hundred self-position (breathing in 5 mov for twice) 7. Spine Curl (single leg stretches) 3 times each side for 5 sec 8. Coordinator 3 × 10 (alternative leg and arms up) 9. Half roll down 3 × 10 10. Oyster 3 × 10 (heels down + knee support) 11. Single leg Kick 2 × 10 12. Inner thigh lifts 2 × 10 13. Oblique ankle reaches 3 × 10 14. Single leg stretches 3 × 10 15. Backstroke 2 × 10 16. Saw 3 ×	1. Pumping calf 2 × 10 2. Squat 2 × 5 *Lying on the mat* 3. Shoulders drops 3 × 10 4. Bridge (arms up and down) 3 × 10 5. The hundred- double leg straight (breathing in 5 mov for twice) 6. Spine Curl (single leg stretches) 3 times each side for 5 sec 7. Coordinator 3 × 10 8. Criss-cross 3 × 10 alternative touch knee/ankle 9. Oblique ankle reaches 3 × 10 10. Backstroke 3 × 10 11. Scissors 3 × 10 12. Oyster 3 × 10 (heels up + knee support) 13. Single leg Kick 2 × 10 14. Inner thigh lifts 2 × 10 15. Saw 3 ×
cool-down (30 seconds)	
1. Hip roll 2. Straight leg hamstring lateral cross 3. Rocking with the arms supporting the body 4. Single leg stretches 5. Calf -stretching 6. Rolling trunk	

- Small items of equipment were used in chapter 5 for the RCT study, such as resistance bands, rings, blocks, the spiky ball and foam rollers (See figures 14 to 18 below). This study included the colours yellow, green and blue bands.

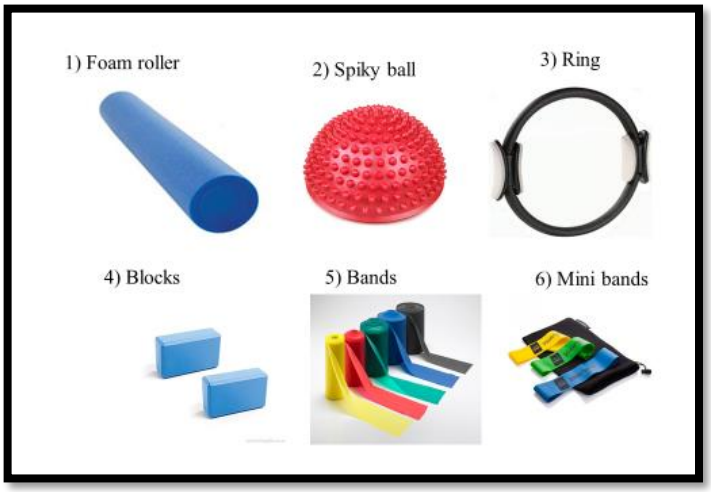

Figure 14 Pilates Accessories

Figure 15 Exercises on the Mat

Figure 16 Exercise's in standing position

Figure 17 Exercises on the Mat and Foam Roller

Figure 18 Exercises adapted for older adults

- *Exercises in the standing position (see on figure 16)*

A) Breathing

Initially, participants performed exercises in a standing position. For the breathing exercise, participants held a ring. They were asked to squeeze the ring when they exhaled and relax when they inhaled. This was repeated 10 times. After that, participants performed the breathing exercise while raising and lowering their heels (calf pumping) or squatting, in line with the six principles of Pilates. This was a set of two with 10 repetitions.

B) Squats

In the first week, the participants performed traditional squats; by the fourth week, this was expanded to include a walking squat side to side. At eight weeks, the forward lunge with mini bands was performed and evaluated. The mini bands were used to improve resistance. For the first set of 10 squats, the band was positioned below the knee and for the second set of 10 squats, the band was positioned over the knee.

C) Balance/Proprioception

Participants performed two exercises in the standing position on the spiky ball. The exercise involved walking side to side over the spiky ball, starting with the left or right foot on the ball with the opposite leg extended in front; this exercise focused on balance control. In the first week, they performed the exercise for five minutes.

The squat position exercise with the heels over the ball and the toes on the floor was performed to give more stability to the older adults. This was repeated 10 times. In the fourth week, if the participants felt more stable, they could stand with their whole foot over the ball.

- *Evaluation on the Mat with accessories (see figure 17)*

The participants' progress on the mat Pilates exercises started after the third week (See - chapter 5). Mat Pilates exercises started after the third week: in the second class, the bridge exercise had the participants place a ring between their knees and move their arms up and down. They performed a set of three of these exercises with 10 repetitions.

In the fourth week, the exercise of oblique ankle reaches and the leg in front stretch with band were included (set of three with 10 repetitions).

In the fifth week, plantar flexion with band in the sitting position was added (set of three with 10 repetitions). The ring was placed between the knees for the hundred (double leg up with bench knee) exercise. Other exercises included double leg stretching with band and rolling like a ball (set of three) and siting positioned for the single leg stretching exercise (set of three held for 30 seconds).

In the sixth week, for the bridge exercise, participants held their hips up for 30 seconds (increasing their time from the first week). In the spine curl exercise, participants held the single leg stretched up for five seconds and repetition was set of five times each leg.

In the seventh week, the evaluation of the exercises included accessories, such as: the bridge exercise with blocks positioned under the feet, the blocks supporting the forearms exercise and the hundred (double leg stretch up) with a ring positioned between the ankles. Mini bands were included for the following exercises: bicycle exercise, front to back leg sweeps, oyster, inner thigh lifts, single leg kicks. In a lying position on a roller, participants kept their spine on the accessory and raised their leg (set of 10 repetitions per side). In a sitting position on a roller, participants

rolled their hips forwards and backwards. After that, participants leaned forward while keeping their hips back and kept their leg stretched (spine stretch forwards).

In the tenth week, for the squat with the ball exercise, participants who felt stable enough to do so put their foot over the spiky ball. For the lying position on the roller (coordinator) exercise, participants kept their spine on the roller and practiced the coordination exercise with lower and upper limbs (single leg lifts and right arm raises when exhaling and the opposite lowering when inhaling). In the sitting position, participants sat on the roller and put their hips forwards while lifting one leg up.

- *Exercises adapted for older adults (see figure 18)*

A) In the rollover exercise, a band was used to facilitate the movement of the body to move up and down during the exercise because the older adults lacked core strength and mobility. The exercise following double leg stretching with a band, rolling like a ball and spine forwards. 1: participants moved from a position of lying on the floor to sitting on the floor. 2: during the movement of sitting on the floor to lying on the floor and raising the legs up, participants moved the hips forwards and backwards to balance the body and push the body down. 3: the participants then sat and executed the 'spine stretching forwards' exercise for 30 seconds. B) In the bicycle exercise, the participants kept their hips on the floor (see figure- chapter 3).

At the beginning of the study, the practice regarding Pilates accessories until the participants became more familiar with the accessories.

The instructor paid more attention to the older participants when carrying out the exercises with the foam roller. Most of the participants forgot to or intentionally did not squeeze the ring during the bridge and the hundred exercise.

When using the blocks, the position of the participants' feet must be stable on the block. The foot tends to naturally fall into an abduction or adduction position. The participants used the small band for the lower limb exercises on the mat. In the beginning, participants were not focused on their posture and the movements. Participants forgot to use the principles of Pilates when they attempted to perform the movements.

3.4.5.6 Home-based

The instructor recorded the home-based exercises using a camera-iPad and edited the video exercises using MOVIEMAKER at NUI Galway. The participants received a booklet with the names of the exercises and the sequence in which to perform them in (see Table 5) the first class. The participants also had access to the home-based Pilates exercise video via a Dropbox link in their email. For home-based Pilates exercises, participants were advised to perform these three times a week for 30 minutes and not on the days of the supervised classes.

Participants learnt the six principles of exercise, as well as how to perform the exercises based on the six principles. The six principles of Pilates are flow, control, precision, centring, breathing and concentration (Kloubec, 2011). The breathing principle of Pilates was included in the supervised class in the first week and for the home-based exercises. The instructor advised the participants about how to execute the movement using voice command as follows: 1) place your hands on your ribcage and expand, at the same time, try to contract your core and stabilise your spine; 2) exhale through the mouth between the teeth, when listening to your breath, you must contract the muscles of the abdomen and at the same time expand the posterior ribs; 3) inhale through your nose and expand your ribcage sideways, exhale through your mouth and contract your abdomen muscle. Participants were asked to perform the exercise at home for ten repetitions or for as long as they could perform it. During the exercises, the movements of the lower and upper limbs must connect with the breath. When the participant inhales, they must open their upper or lower limbs and when they exhale, they must close their upper or lower limbs. The movements required accurate execution to control the biomechanical aspects, such as the muscle and joint positions.

Home-based exercises involved similar exercises as those in the supervision class: warm-up, squatting on a chair, heels up with hands support, bridging with a pillow, single-leg stretching without arms movement, oyster, the hundred, roll-up and the coordinator exercises. There were four warm-up exercises, 6 exercises on the chair, 13 mat exercises and 4 cooldown exercises (See table 5).

Table 5 Home-based Pilates exercise

Warm up	**HOME-BASED PILATES**
Standing position	
	1. Breathing 2. Rolling trunk 3. Holding shoulders 4. Stretching (arms, neck)
Exercises with chair	
	1. Pumping calf 2. Thigh 3. Squat 4. Raise lateral leg 5. Raise the leg in front 6. Stretching abductors
Mat Pilates	
	7. Stretching (breathing sitting, stretching- bent knee hamstring stretch and knee straight, hip roll) 8. Bridge with pillow 9. Bridging 10. Single Leg stretching 11. Bicycle (forward and backward) 12. Double leg Straight up (basic –flex knee and Inter- knee straight) 13. Coordination (leg and arms in opposite side) 14. Lateral leg 15. Oysters 16. leg seeps front to back 17. Rolling like a ball 18. Roll up
Cool-down	
	1. Bent knee hamstring stretch 2. Straight leg hamstring stretches 3. Child position 4. Supported on the forearms

3.4.6 Outcome Measures

3.4.6.1 Questionnaires

The International Falls Efficacy Scale (short FES-I) short version questionnaire is reliable and valid and contains seven questions evaluating an individual's concern about the possibility of falling, with responses ranging from 9 ('not at all concerned') to 4 ('very concerned'). The short version (short FES-I; n = 704) and the test of reliability and validity of the short FES-I uses data from a Dutch survey (n = 300) (Kempen et al., 2008) (Appendix 4).

The Physical Activity Assessment Tool (PAAT) is a quick test that can be completed in a maximum of 7 minutes. This test measures the type, frequency and duration of exercises. The PAAT assesses moderate and vigorous intensity activities in four PA domains, including the leisure, occupational, household and transportation domains, in the last 7 days, Additional questions are included for usual activity to rate participants as 'active' or 'underactive'; moreover, participants are rated as being more active, less active or about the same in terms of whether they have accumulated more than 150 minutes per week of moderate to vigorous physical activity (MVPA) or more than 60 minutes per week of VPA. PAAT is correlated to IPAQ long-form questionnaire ($r=0.562$, $p<0.001$) and MTI accelerometer ($r=0.392$, $p=0.015$) for MVPA (Meriwether et al., 2006) (Appendix 5).

The feedback and a post-test survey, in which the participants were asked the following questions: Did you do all exercises in the correct way? Did you do all the exercises in time? In general, how did you find the exercises, and a four-point scale

was used to record the answer of this question: very easy, easy, difficult, or very difficult.

3.4.6.2 Physical tests

The Functional Reach Test (FRT) has high inter-rater reliability (ICC = 0.98) and can predict future falls among elderly persons (Duncan et al., 1990). The test has been repeated a total of three times and the average excursion, in centimetres, is the FRT score (Johnson et al., 2007). Average values in community-dwelling older adults are between 27.2-25.5 to 28.9 cm (Bohannon et al., 2017). A ruler was used to measure the distance (cm) from the initial point to the end over three trials.

The Time Up and GO (TUG) test is a reliable, cost-effective, safe and time-efficient way to evaluate overall functional mobility (Kear et al., 2017). It is a sensitive and specific tool used to identify community-dwelling adults who are at risk of falling, including older adults who have balance impairment and live independently within a community (Shumway-Cook, 2000). The TUG test is recommended by the American Geriatric society (AGS) and British Geriatric society (BGS) for screening the risk of falling (JAGS, 2010). Older adults who score ≥ 13.5 seconds to complete the TUG are classified as at risk of falls with an overall accurate prediction rate of 90% (Shumway-Cook and Woollacott, 2000).

The Footwork Pro pressure platform (Franklin, New Jersey, USA) was used to measure postural balance and evaluate the parameters associated with falls risk in older adults (Piirtola and Era, 2006). Technical Specifications for the Footworkpro Amcube-UK (2010) active area are 400x400, sensor Size: 7.6 x 7.6mm, calibration: 100% digital, Plate Thickness: 5mm. Sensor Type Capacitive; total size: 575 x 450 x 25 mm, number sensors: 2.704 (calibrated) (Appendix 13). Participants performed the test in bipedal (BI) and single leg standing positions for the right side (R) and

following sequence for the left side (L) under eyes opened conditions. The CoP variables in the mediolateral (ML) and anteroposterior (AP) sway were measured.

The GAITRite® electronic walkway system was used to assess the participants' gait analysis (Appendix 13). The technical specifications of this system include an electronic walkway that is 6 m long with 18,432 pressure sensors, measurement area is 61 cm wide and 488 cm long (https://www.gaitrite.com/). The variables of spatiotemporal parameters of gait such as step time (s), step length (cm), stride length (cm), swing time (s), stance time (s), double support time (s), swing (CV%) of cycle, stance (CV%) of cycle and velocity (cm/s) were evaluated.

3.4.7 Procedure

All assessments took place in the Podiatry Laboratory, Áras Moyola, NUI Galway and took approximately one hour per participant. Participants performed the tasks individually one week before and for one week after the six-week intervention. The feedback of Pilates and survey were addressed after the six weeks of intervention.

The demographic characteristics of age, gender, height, body mass index (BMI) and cognitive ability (MoCA) were measured (Appendix 6).

The participants were evaluated using questionnaires such as the FES-I (short) (Kempen et al., 2008) (Appendix 4) and the PAAT (Meriwether et al., 2006) (Appendix 5). The participants were asked to perform a physical test wearing their own comfortable shoes for three trial exams and the average was used for the analysis of the FRT and TUG test. For the FRT, the participants were required to stand next to the wall (Duncan et al., 1990). Individuals were instructed to place their feet hips-width apart, flex their shoulder to 90 degrees, raised their arm and reach forward as far as possible without taking a step.

For the TUG test, the participants stood from a chair, walked for 3 m, turned around, walked back to the chair and sat down. The average of the three trials was used for purposes of analysis (Wrisley and Kumar, 2010). Participants were asked to walk as fast as they could.

The participants were asked to start walking for one metre before the GAITRite® electronic walkway system and after the mat. The Footwork Pro pressure platform participants were asked to perform the balance tests in the same order. Participants were barefoot and looked straight ahead, with their arms beside their bodies. The measurements were performed first in bipedal standing and then in the single-leg stance—the right side first followed by the left side. Participants were asked to maintain each balance test performance for ten seconds (Tanaka et al., 1999). For three trials each side.

3.5 Analysis of Exploratory Study

As the sample size was small data were presented as scores by number *(n)* of participants. Software Package for the Social Sciences (SPSS) v22 was used.

3.6 Results

Of six participants included, and three participants dropped out of the study. Participants reported serious advert events such as having surgery (n = 1) and a consequence of a fall (n=1). Another participant had no reason (n = 1). With regards to the reported fall, one female fell after the study was completed. This participant was not able to perform the post-test physical test due to spraining her ankle. Thus, three participants (1 man /2 women), remained in the Pilates intervention programme and completed the entire assessment. The age of the participants ranged

from 65–71 years old, with a mean age of 68.33 ± 3.05 years; height, 1.62 ± 0.05 cm; and BMI, 22.41 ± 5.0 kg/m^2.

3.6.1 Pilates Exercises

Initially in the Pilates intervention, the progress of the participants in group 1 was slower than those in group 2. It became apparent that group 2 were better able to perform the exercises correctly and at an earlier stage than those in group 1. This was despite the fact that both groups undertook the same exercises and spent the same amount of time with the PI in the supervised classes. As participants withdrew from the study the groups were subsequently amalgamated to form one study group.

Two of three participants handed back the sheet notes to the PI in the post-test. The easiest exercises were rolling like a ball, chair exercises and hip roll and the difficult exercises were coordination, oyster, leg stretching and cycling backwards.

Participants could better engage the six principles for the bridging and "the hundred" exercises, which required flowing with precision and coordination while breathing in and out in the third and fourth week.

The home-based participants reported: during week 1: one felt the exercises were difficult and they could complete the exercises within 30 minutes and two did not perform the whole of the exercise home programme on the same day. In the fourth week, group 2 found that the exercises became easier to perform. In group 1, one participant still thought it was difficult to perform the exercises. Two participants used the booklet more than the video. Three required a more active voice command from the PI when changing the exercise on the video. One could not perform the roll-up exercise even after ten sessions.

3.6.2 Findings

The TUG measure showed that the pre-Pilates training scores were 8 to 9.60 seconds higher than the test scores of 6.86 to 8.70 seconds post-Pilates training. The FRT participant scores were lower in the pre-test with scores of 18.20–33.50 cm, but post-test scores were higher at 25–35 cm. Further, the FES-I indicated pre-test scores of 6–9 and post-test scores of 7–11 (See TUG, FRT and FES-I scores in the table 6 below).

Table 6 TUG, FRT and FES-I presented the scores by each participant for the pre-test and post-test six weeks.

Variables	*Pre-test (n)*	*Post-test (n)*
FES	6 (2)	7 (1)
	9 (1)	8 (1)
		11 (1)
TUG (s)	8 (1)	6.86 (1)
	9.48 (1)	8.19 (1)
	9.60 (1)	8.70 (1)
FRT (cm)	18.20 (1)	25 (1)
	26.75(1)	28 (1)
	33.50 (1)	35 (1)

Pre and post-test scores by *(n)* number of participants to each measure: International Falls Efficacy Scale FES-I, Time Up and Go (TUG), Functional Reach test (FRT).

The PAAT questionnaire of physical activity showed the level of activity of participants over the last seven days. At the pre-test, the participants reported performing physical activity on four, five and seven days a week for twenty, thirty and sixty minutes, respectively. The post-test revealed that two participants performed physical activity for seven days a week, in total of thirty-seven and 96 minutes each participant; however, one participant had not to perform any physical activity.

In terms of VPA, at the pre-test, no participants performed any VPA. The post-test revealed that one participant started to do VPA for at least 10 minutes each day for

seven days and another participant increased the frequency and time from four to seven days, with an average of 30–60 min a week. The results also showed that one participant accumulated 156 min of total physical activity time in one week.

Participants were asked about their level of physical activity after the last 3 months. All participants answered, “About the same.”

The plan for the subsequent six months in the pre-test showed that all participants intended to do exercises. However, in the post-test, two participants reported doing regular physical activity for the previous 1–5 months and one intended to continue doing physical activity for the subsequent 6 months.

Postural balance scores for the mediolateral directions for bipedal performance were lower in the post-test than in the pre-test. The single-leg standing performance in the mediolateral direction showed increased scores for the right side and decreased scores for the left side. The anteroposterior direction showed a decreased score for the right side and an increased score for the left side (See table 7 below).

Table 7 Postural balance presented the scores by each participant for the mediolateral and anteroposterior directions variables

Variables		*Pre-test*	*Post-test*
Mediolateral cm	BI	2.55	4.15
		5.93	7.37
		11.46	7.90
Mediolateral cm	R	12.51	11.50
		3.83	8.80
		5.75	5.10
Mediolateral cm	L	9.55	6.26
		9.10	7.04
		6.10	6.17
Anteroposterior cm	BI	2.20	2.93
		6.36	4.08
		5.79	20.48
Anteroposterior cm	R	4.45	3.80
		6.38	3.50
		9.41	2.55
Anteroposterior cm	L	4.76	2.68
		5.04	9.62
		9.25	9.01

Data: scores by each participant
Abbreviation: right (R), left (L), bipedal (BI) conditions

Regarding the spatiotemporal parameters of gait, there were increases in scores after Pilates for velocity (cm/s), step length (cm) and stride length (cm) on the right side. A decrease in scores after the Pilates programme was found for step length (cm) and stride length (cm) on the left side and for step time (s), swing time (s), stance time (s), double support time (s), swing % of cycle and stance % of cycle (See table 8 below).

Table 8 Spatiotemporal parameters of gait presented the scores by each participant

Variables	*Pre-test*	*Post-test*	*Pre-test*	*Post-test*
Velocity (cm/s)	149.20	155.70		
	133.20	153.70		
	110.40	126.30		
	Right		Left	
Step Time (s)	0.459	0.474	0.554	0.470
	0.519	x	0.537	0.482
	0.582	0.532	0.575	0.535
Step Length (cm)	71.24	74.08	79.96	72.80
	69.99	x	70.19	73.04
	64.59	69.20	63.00	65.66
Stride Length (cm)	159.70	146.20	141.41	147.99
	141.20	147.58	139.82	148.70
	127.49	136.56	128.53	134.90
Swing Time (s)	0.490	0.375	0.465	0.380
	0.217	0.389	0.422	0.398
	0.400	0.369	0.400	0.375
Stance Time (s)	0.575	0.567	0.549	0.560
	0.675	0.594	0.648	0.587
	0.735	0.679	0.733	0.668
Double support time (s)	0.217	0.187	0.242	0.190
	0.276	0.222	0.277	0.225
	0.311	0.283	0.319	0.280
Swing % of cycle	0.460	0.398	0.459	0.405
	0.372	0.383	0.382	0.390
	0.362	0.364	0.365	0.373
Stance % of cycle	0.540	0.602	0.541	0.596
	0.628	0.617	0.618	0.610
	0.639	0.630	0.634	0.620

Data: scores by each participant. X: missing data

3.6.3 Finding's summary

- After six weeks of Pilates exercises, participants had an increase in their scores regarding the mobility and physical activity of healthy older adults.
- The participants decreased their scored times on functional mobility, postural balance for mediolateral directions by bipedal, single-leg on the left side performance and anteroposterior directions for single-leg standing performance on the right side.

- The older adults walking patterns had an increase in scores in velocity and a decrease in temporal parameters of gait, such as swing time, stance time and double support time, were noted after Pilates.

- In relation to the assessments, this study suggests future changes for the following cohort study regarding to the fear of falling and physical activity questionnaires. The booklet of home-based exercises (See in table 9) which each assessment changes will be explained in the discussion section 3.7.

Table 9 Summary of recommended changes

	Study 1 -Feasibility Study	**Study 2 – Cohort Study**
Assessments	FES-I PAAT	FES-16 Falls past year (baseline) IPAQ
Pilates exercises	Supervised Home-based exercises described with no picture	Increased repetitions, more exercises included Home-based booklet with pictures
Questions of class/home exercises	Addressed Pilates questions (7)	

3.7 Discussion

The present study explored the effects of six weeks of traditional mat Pilates on mobility, functional mobility, physical activity, postural balance, fear of falling and spatiotemporal gait parameters. Based on the findings of the present study, the feasibility study informed the cohort study and the methodological approach subsequently adopted as detailed below:

The present non-experimental study was suitable for identifying variables, refining assessments, addressing questions and revising exercises. Based on the results of the present study, the questionnaires on physical activity and fear of falling in the assessment were revised. Specifically, FES-16 has been included and Short FES-I

(Kempen et al., 2008) excluded. The FES-16 (Yardley et al., 2005) questionnaire is more complete than the FES-I questionnaire; as such, the former includes additional important questions, such as question 11, which refers to walking on a slippery surface and question 14, which refers to walking on uneven floor. The participants were also asked if they have fallen in the past year. In the present study, gait and balance of the participants were evaluated. Therefore, the above questions were considered important to include.

In addition to the Short FES-I, the PAAT questionnaire were excluded. The PAAT is a questionnaire used for epidemiologic research; however, participants can misinterpret the questions due to cultural differences in the activities or terminology used (Meriwether et al., 2006). The International Physical Activity Questionnaire-Short Form (IPAQ) (Craig et al., 2003) is used for the assessment of older adults. The validity and reliability of the IPAQ-short form have been confirmed by studies in twelve countries that evaluated the metabolic equivalent of task (MET) (Kurtze et al., 2008). This questionnaire is quick and easily accessed for specific age groups of adults and older adults for rationality calculation tasks.

A previous study involving eight-weeks of mat Pilates using accessories suggested that the AP direction parameters were associated with falls risk, but no significant changes in postural stability were noted in the ML direction; however, the sample size of that study was small (n=9) (Newell et al., 2012). In contrast, in another study involving twice-a-week exercise revealed that when training on an unstable surface with eyes closed, balance improved in the ML direction, but no changes occurred in the AP direction; however, this study included only seven participants (Kaesler et al., 2007).

In our Pilates intervention, most participants performed the exercises well. At the third week, the participants improved their level from the basic to intermediate level of exercise. From the second to last week (6th week), the number of repetitions, sequences and the intensity of exercises in the class increased. The Pilates instructor modified the difficulty level of exercises according to the participants' progress (Kuo et al., 2009).

The roll-up exercise was particularly difficult for the participants according to the PI's observation. At the end of the six-week intervention, some of the participants could not easily move their trunks upward. This may have been due to the abdominal muscles required for a strong core to move their hips and trunks up. According to Rose (2010, p. 14), older adults have a weaker musculoskeletal system and may require more frequent exercise to improve their movements. This appears to corroborate Silva et al.'s (2015) study, which found that the roll-up exercise results in the contraction of the lower abdominal muscles. Therefore, this exercise can be used as an early intervention for rehabilitation and training programmes (Silva et al., 2015).

In the subsequent study (study 2), additional exercises for postural strength, which focused on the trunk and 'powerhouse', were included. Trunk control is a desired outcome for functional movements and requires successful integration of all its components to maintain a normal orientation to the gravity (Anderson and Spector, 2000). Exercises focusing on the 'powerhouse' worked on the abdominal, gluteal and paraspinal muscles. The objective of these exercises was to stabilise the core musculature and then proceed through a controlled range of motion (Sorosky, 2008).

The home-based exercise booklet was personalised and after revision, some exercises that require a chair (stretching exercises and the standing up exercises for leg) and two exercises that require a Pilates mat were included (the coordination and the bicycle exercises). These exercises included in the booklet had the objective of making the participants more quickly familiarised with the exercises, which the participants had the chance to practice in class with the instructor and at home. Pictures of the PI executing each exercise were included in the booklet and DVD to make it easier for the participants to replicate the exercises.

In addition, after completing the Pilates programme, participants were permitted to keep the booklet and DVD or online video access to continue practicing the exercises at home.

It was a challenge to introduce Pilates to older people. During the intervention, some individuals asked the PI questions regarding exercises performed in class and at home. From their feedback (questions and sheet notes), the PI wished to understand how difficult or easy it was for these highly active elderly people to perform the exercises. In addition, the PI sought to understand whether the exercises proposed for these individuals actually affected their activities on the day after the Pilates class and their other daily activities over six weeks at the end of the programme.

Participants were motivated to continue Pilates for more than six weeks. Mat Pilates exercises are cost-effective: it does not need expensive equipment or a studio set-up unlike regular Pilates and the individual only must use the gravity of the body at all difficulty levels of exercise.

3.8 Limitations

The present study was exploratory due to the small sample size and no definitive conclusion could be drawn based on the results. Moreover, the results of spatiotemporal parameters of gait, such as step length and stride length, differed between the two sides, with the right side showing increased and the left side showing decreased scores after Pilates. Finally, the scores for postural balance in the ML (R), AP (BI) and AP (L) directions also increased. However, because the sample size was so small no inferences about the data can be made.

Regarding to missing data on the right side occurred when the PI were extracted manually data from the program. It can be biased on the results.

3.9 Clinical Implications

While performing exercises in the class, the participants faced difficulties in coordination during the kick double foot and backstroke exercises. In the ‘front to back leg sweep’ exercise, the participants incorrectly performed point and heel and flexed the knee. In the single-leg stretching exercise, the participants faced difficulties in moving the ankle and foot as point and heel. The participants also found it difficult to sit on their heels during the child position posture. In addition, during the roll-up exercise, the participants found it difficult to pull their trunks up without catching their legs. Additionally, the person who is overweight may need more effort to perform exercises such as to maintain the hip up and the abdominal exercise. However, variations of exercise will be needed when these participants are performing the exercises.

3.10 Conclusion

Participants in the six-week Pilates programme received an educational introduction, learnt to perform the exercises from a professional and benefited from

participating in supervised classes and using the home-based exercises booklet. The traditional mat Pilates programme can be offered to community-dwelling older adults and can be set up anywhere. This study was feasible to the Pilates intervention, and it could be addressed some suggestions to future researchers regarding the recruitment; the social media and the local journal there was a great impact on the community of Galway. The Pilates exercises protocol improved during the period of intervention and the participant's feedback were important to address question for the survey and the evaluation of exercises. Pilates may reduce falls risk and promote health and well-being however, further studies with large sample size, randomised control groups are warranted to evaluate the outcome measures.

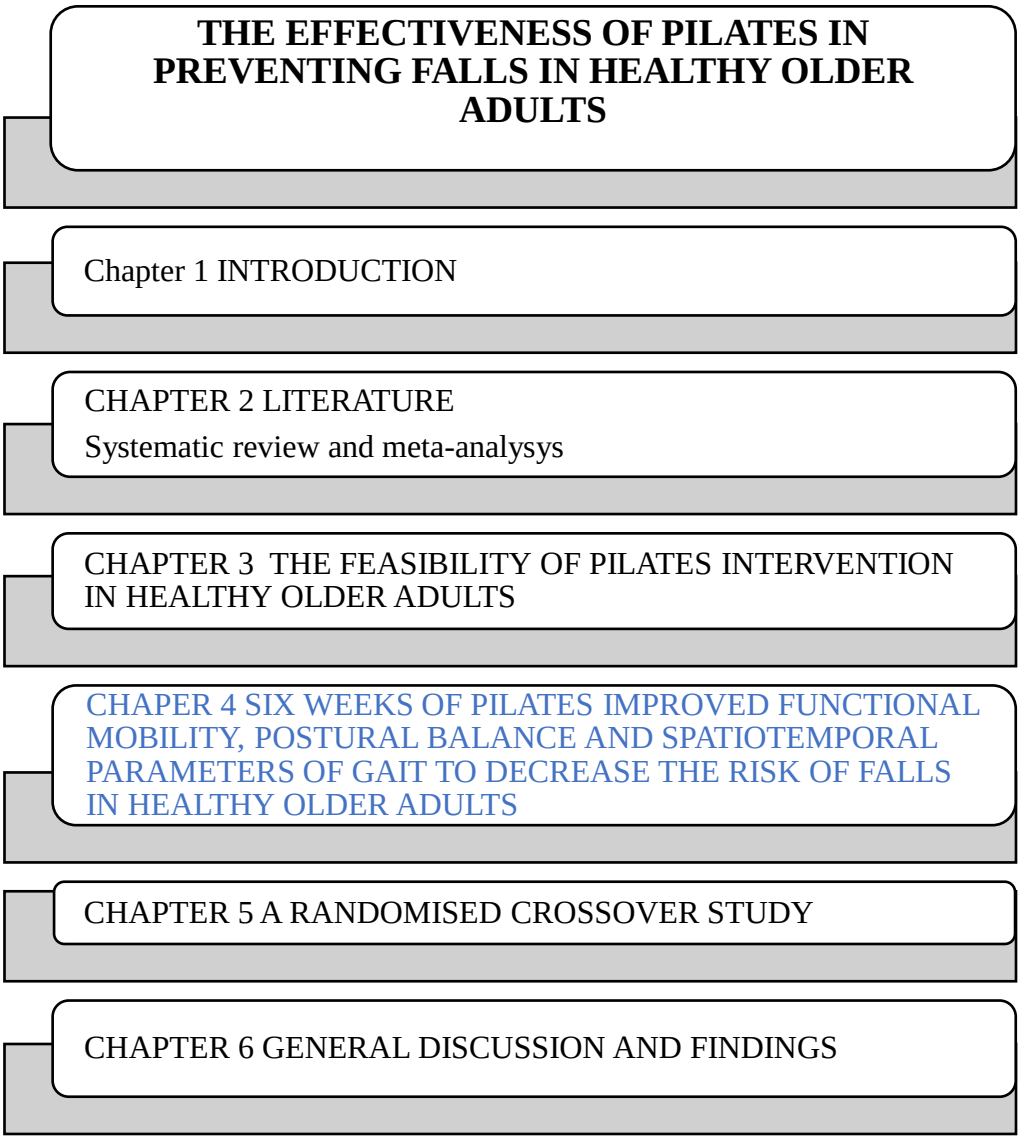

Figure 19 Layout of the thesis

CHAPER 4 SIX WEEKS OF PILATES IMPROVED FUNCTIONAL MOBILITY, POSTURAL BALANCE AND SPATIOTEMPORAL PARAMETERS OF GAIT TO DECREASE THE RISK OF FALLS IN HEALTHY OLDER ADULTS

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Abstract

Objective: To determine the effectiveness of Pilates exercises on falls risk factors.

Design: Prospective cohort, pre-test post-test study. Participants were selected using convenience and snowballing sampling. Pilates classes were held twice weekly for six weeks (one-hour sessions) with a supplementary home programme.

Methods: A test of cognitive function, the Montreal Cognitive Assessment (MOCA), was employed to determine eligibility for inclusion. The following fall-predictor variable measures were employed: the 16 item Falls Efficacy Scale (FES), the short International Physical Activity Questionnaire (IPAQ), the Functional Reach Test (FRT), the Timed Up and Go (TUG), the GAITRite® system, Platform FOOTWORKpro. Multivariate analysis ANOVA with time as within subject factor was used to test for differences between pre and post-test scores adjusted for the factor Pilates.

Results: twenty-seven participants completed the study, mean age =70.4 (SD =4.5). After adjusting for the effect of the factor Pilates "previous experience of Pilates", statistically significant differences were identified in the following domains: The TUG ($p<0.001$), FRT ($p<0.001$), velocity, swing and stance time and the Mediolateral sway ($p<0.05$). A significant difference was found between pre and

post-test for anteroposterior sway in those with experience of Pilates ($p<0.05$) and interaction between time and Pilates experience in Physical Activity ($p<0.05$).

Conclusion: Findings suggest that functional mobility, mobility, spatiotemporal parameters of gait, postural balance and physical activity improved in healthy older adults after 6 weeks of Pilates with a supplementary home programme.

Key-words: Pilates, older adults, falls, gait, balance.

4.1 Introduction

The World Health Organization (WHO, 2018) reports that the number of people worldwide aged 60 years or older will increase from 900 million to 2 billion between 2015 and 2050. Falls are a significant public health problem for older adults; it is estimated that 646,000 people die from falls worldwide each year (WHO, 2018). Furthermore, falls are the second-leading cause of more than 17 million disability-adjusted life years lost across the globe each year (WHO, 2018). It is reported that healthcare systems provide medical care for 37.3 million individuals who have had falls (WHO, 2017) per annum, thus highlighting the significant burden associated with falls. Gait and balance issues are the primary cause of falls in older adults and are related to increased morbidity and mortality as well as lower levels of functioning (Salzman, 2010), including weakness, gait deficits, confusion and polypharmacy (Rubenstein, 2006). These deficits in gait, postural control, changes in body composition and fear of falling are important risk factors for falling (Hita-Contrera et al., 2016). Addressing these risk factors can reduce fall rates and therefore, the adverse outcomes associated with falls. Interventions such as falls risk assessments, exercise programs (Rubenstein, 2006) and physical activity are beneficial in lowering lifestyle-related diseases and regular exercise programs can improve stability and decrease the risk of falls in older adults and those with balance impairments (Thomas & Magal, 2014). The findings of a recent systematic review indicate that interventions with holistic exercise such as Pilates and yoga were more effective in decreasing the fear of falling than strength, balance, endurance, strength training and combined exercises (Kruisbrink et al., 2020).

Studies have shown that Pilates exercise decreases the risk of falls (Pata et al., 2014; Barker et al., 2016; Josephs et al., 2016; Roller et al., 2017) and improves functional mobility (Kaesler et al., 2007; Bird et al., 2012; Pata et al., 2014; Josephs et al., 2016; Bertoli et al., 2017). Pilates intervention, with supplementary at-home exercises, has been found to improve balance confidence and balance in less than 50 hours of Pilates in individuals at risk for falls (Josephs et al., 2016). Recently, Casonatto and MayumeYamacita (2020) highlighted that Pilates training is useful to improve balance in older adults and the duration of the intervention, amount of Pilates per week and the quality of the studies were not linked to the magnitude of the effect on postural balance. Furthermore, a recent study found that after twelve weeks of Pilates training, older women improved balance confidence, fear of falling and postural stability (Aibar-Almazán et al., 2019). Badie and colleagues found a marginal reduction in fear of falling in older women after eight weeks of Pilates training (Badie et al., 2017). Pilates has also been shown to reduce the number of falls. In a randomised controlled trial (RCT) the Pilates exercise group showed a lower number of falls than the control group with the average number of falls 0.37 versus 1.30 in the control group after a 12-week program of Pilates. However, the average age of the participants in the control group (78 years) was higher than that of the Pilates group (72.8 years) (Irez-Babayigit et al., 2011). Furthermore, in a previous study the authors reported (in percentage) the number of falls during the eight-week program in participants at risk for falls whereby 88.5% participants reported at least one fall after four weeks and 77.1% participants did not report a fall after the eight-week program (Pata et al., 2014).

Studies have investigated the effects of Pilates on the spatiotemporal parameters of gait impairment in subjects with diseases such as stroke (Shea & Moriello, 2014),

chronic hemiplegia (Roh SuYeon et al., 2016) and multiple sclerosis (Kalron et al., 2017); and in healthy subjects (Newell et al., 2012; Wonjae Choi et al., 2019) only, Shea & Moriello (2014) used the GAITRite® system. However, it is still unclear whether patterns of gait are improved after Pilates training that also included physiotherapy and occupational therapy exercises (Shea & Moriello, 2014). The Pilates intervention did not result in significant improvement when compared to physiotherapy exercise (Kalron et al., 2017) and once-weekly training (Kalron et al., 2017; Newell et al., 2012). No significant difference in the asymmetry index of kinematic gait parameters was found between the intervention and control groups (Roh SuYeon, et al., 2016).

Pilates training has not yet been scientifically proven to be an effective exercise in decreasing fear of falling and improving spatiotemporal gait parameters and physical activity in healthy older people. The effectiveness of Pilates training with short- and long-term intervention still needs to be investigated to reduce the risk factors of falls in healthy older adults. This study investigated whether a Pilates intervention of six weeks with a supplementary at-home program was effective in reducing falls risk factors in older adults (≥ 65 years). The study aimed to identify whether mobility, functional mobility, spatiotemporal gait parameters, postural stability, fear of falling and physical activity changed over six weeks of Pilates training. A further aim was to establish whether there was an effect of prior experience of Pilates in all variables and interactions.

4.2 Methods

A cohort pre-test and post-test design was used in this study. Participants completed a pre-test one week before starting the Pilates exercise intervention. A post-test was completed one week after the six-week traditional Pilates program

with a supplementary home-based intervention program. The methodological approach employed in this cohort study was informed by the findings of an initial pilot study.

4.2.1 Participants

Participants were recruited through advertisements in newspapers and at meetings in communities of older adults in Galway City, Ireland. Convenience and snowball sampling were used to recruit participants. Inclusion criteria for the study included healthy older adults who were able to attend the Pilates sessions frequently, had not had surgery in the past six months, had no restriction recommended by their General Practitioner and had a Montreal Cognitive Assessment (MoCA) score of over 26 (Nasreddine et al., 2005). Those excluded had a MoCA score of less than 26, had experienced a fall in the last six months, had acute or chronic musculoskeletal pain, for instance, chronic back pain, (Barker et al., 2016) and/or acute inflammation (injury: knee, hip, shoulder, i.e., tendinitis) and/or illness: i.e., unstable blood pressure, myocardial infarction or any disease that could limit the ability to perform the safe exercise (Barker et al., 2016), had a history of neurological impairment, had medical and pharmacologic contraindications to exercise, vertigo or had a vigorous exercise routine already. The research was approved by The University Research Ethics Committee at the National University of Ireland Galway (NUI Galway) in 2015. There were 42 people interested in participating in the study. After meeting criteria, participants undertook a MOCA test; seven people failed this test and a further three were unable to attend classes frequently. In total, 32 were eligible for inclusion in the study. Five participants withdrew from the study, four females and one male, for poor health (2), back pain (1), unknown (1) and unable to attend frequently (1). No further adverse events occurred (see Fig. 20).

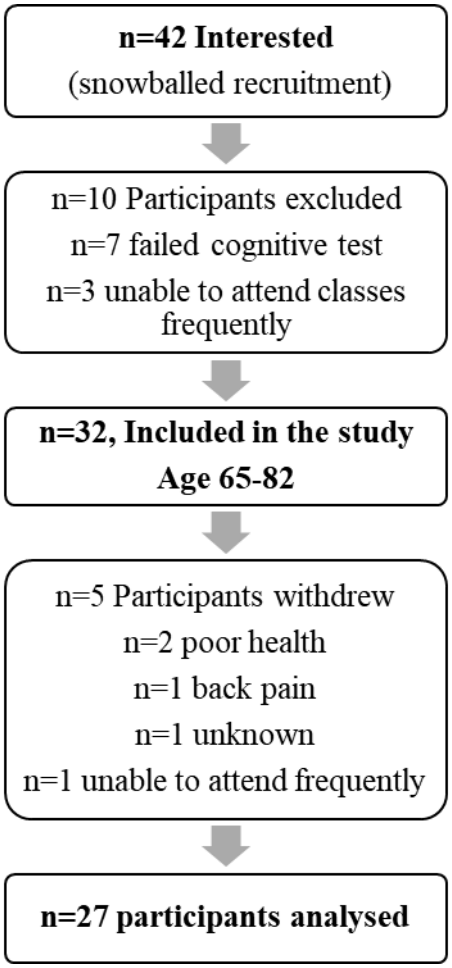

Figure 20 Participant's snowball diagram

4.2.2 Intervention

Pilates classes were held twice weekly for six weeks with one-hour sessions at NUI Galway in Ireland. The exercises were clearly defined before the sessions in the study protocol. The classes were supervised by the instructor, who is a fully qualified physiotherapist and completed courses in Valeria Figueiredo International and Body Control Pilates. The PI supervised participants throughout all sessions. Exercises were adjusted according to ability level if participants experienced any difficulty.

The supervised classes were conducted in groups with a maximum of six participants and were divided into a warm-up, mat Pilates and cool-down. This included performing at a basic level and then moving to an intermediate level of exercises. In general, the practices were focused on the lower limbs (muscles related to gait and balance), core and trunk (muscles related to posture). In each class, the exercises were sets of two to three times with a repetition of ten times per workout. The exercise protocol was based upon previous studies (Pata et al., 2014; Hyun et al., 2014). The supervised exercises were evaluated every three weeks by the instructor (see previous chapter 3).

The class started with breathing exercises: participants learnt how to breathe during the exercise of heels up (pumping calf) without support exercise and breathing exercises on the mat and evaluated to the bridge exercise.

In the third week the breathing on the mat, table-top with bench knee, half-rolldown and single-leg stretching exercises were excluded. After three weeks, the criss-cross-touch knee/ankle and scissors' exercises were included.

Instructions and adaptations of exercise including the bicycle exercise (for which participants kept their hips on the floor) for the home-based, were performed. For the hundred, participants were advised to keep their heads on the floor or put their heads up and were requested to notify the instructor if they experienced pain.

The instructor recorded the home-based exercises using a camera-iPad and edited the video exercises using MOVIEMAKER at NUI Galway. Participants received a booklet at the first class (see Table 4 on previous chapter 3) and had access to the home-based Pilates exercise video via a Dropbox link in their email. The video included the introduction of the six principles of Pilates, warm-up exercises, exercises with a chair (which had standing position), mat Pilates exercises and cool-

down exercises. For home-based Pilates exercises, participants were advised to perform these three times a week for 30 minutes.

In the first supervised class, the instructor demonstrated the exercises and explained the video to the participants. The participants viewed the movements via online video and performed the activities at the same time during the one-hour session. The participants also performed the same exercises in the last supervised Pilates class for the instructor to evaluate their performance of the exercises and to see if they had any difficulties. The instructor received feedback from participants in the post-test. A CD was provided to the participants who were unable to access Dropbox or who could not access a computer; participants could also use the booklet. Participants had the option to choose a time that could fit around their daily schedules.

4.2.3 Outcome Measures

Validated questionnaires and instrumental measures were included for the pre-test and post-test for the risk of falls. The instructor collected data one week before the intervention period started and one week after the intervention. The pre and post-test assessments took approximately one hour, six weeks apart to assess the following outcomes:

Primary outcomes: fear of falling, mediolateral and anteroposterior sway cm (balance) and velocity (cm/s).

Secondary outcomes: functional mobility, mobility, physical activity level (METs) and gait as stride length (cm), swing time (sec), stance time (sec) and double support time (sec).

The following clinical assessments were performed:

The Functional Reach Test (FRT) (Duncan et al., 1990) (Cited in chapter 3).

The Time Up and GO (TUG) test (Shumway-Cook and Woollacott, 2000) (Cited in chapter 3).

Instrumental measures were taken using the GAITRite® system. Specifications (Cited in chapter 3). As with the Moreira et al. (2015) study, the following variables were measured: Velocity (m/sec), Stride Length (cm), Swing Time (sec), Stance Time (sec) and Double Support Time (sec).

The Footwork Pro pressure platform (Franklin, New Jersey, USA) (Cited in chapter 3).

Participants were assessed by face to face for questionnaires, including the (FES) 16-item; participants were required to answer the questions thinking about how they would usually do the activity and how concerned they would be about falling. The following scoring system was used: 1; not at all concerned 2; somewhat concerned 3; fairly concerned 4; very concerned. The total score ranged from 16 to 64 (Yardley et al., 2005) (Appendix 7).

The IPAQ short form measures daily physical activity (Craig et al., 2003). The total scores of walking; moderate and vigorous-intensity activity described the overall level of activity in (METs) metabolic equivalent minutes per week, calculates as the MET intensity multiplied per min for each activity during the last seven days such as walking=3.3 METs, Moderate PA= 4.0 METs and Vigorous PA= 8.0 METs (http://www.ipaq.ki.se) (Appendix 9).

4.3 Statistical Analysis

The sample size chosen was determined by using G*Power software (version 3.1; Universität Düsseldorf, Germany) for a power of about 0.95 (significance level = .05; correlation coefficient = .5; effect size d = 0.8) based on the data research of Kaesler et al (2007) and Newell et al. (2012). This suggests that a high power is possible with 27 subjects to detect a difference of 0.8.

Statistical analyses were performed using IBM SPSS 24.0 (IBM Corp, 2016) and Minitab 17 (Minitab Inc 2017). The Kolmogorov-Smirnov test of normality was checked and the homogeneity test was also carried out for violations of normality of the underlying population. Therefore, the question of sphericity was redundant.

Investigations involved modelling each of the following single response variables: FRT (cm), TUG (sec), FES-16, IPAQ (MET), BIAP/ML (cm) and velocity (m/sec) for variables that had two related measurements for each individual (namely left and right AP/ML which had left and right measurements on each individual. Stride Length (cm), Swing Time (sec), Stance Time (sec) and Double Support Time (sec) were each analysed using a sometimes called doubly multivariate analysis, to account for the fact that not only is there a possible Time effect (the difference between Pre and Post) but also because both sides were measured.

Multivariate analysis was employed to achieve extra power. In all calculations, the effect of Pilates (that is whether a person had prior experience of Pilates) was accounted for (i.e., its effect was removed in the comparison of pre- and post-measurements). In all analyses, the possible interaction between Time and Pilates was allowed. The results of each analysis conducted then measures the main effect of Time, the main effect of Pilates.

4.4 Results

Thirty-two participants were included in the study and 27 completed Pilates exercises. Intention to treat analysis was not undertaken. The age range was 65 to 82 years. Mean age=70.4, SD (4.5); number of falls in the past year: 1.62 (0.68). A higher percentage of females (85.2%) than males (14.8%), had previous experience of Pilates (n=8) (29.6%) – no prior experience of Pilates (n=19) (70.4%), (see table 10).

Table 10 Demographic details of participants

Age (65-82 years)	70.40 (4.5)
Gender (F/M), *n (%)*	F =23 (85.2%) / M=4 (14.8%)
MOCA	27.51 (1.45)
Height (cm)	163.07 (7.45)
Body Mass Index (Kg/m^2)	28.05 (3.99)
Pilates experienced (yes/no), *n (%)*	8 (29.6%) – 19 (70.4%)
Number of falls (past 12 months)	1.62 (0.68)

Mean and Standard Deviation (SD), or *n* (%).
Abbreviation: females and males (F/M), Montreal Cognitive Assessment (MOCA

For FRT, a one-sided alternative was tested. Specifically, since it was of interest to test to see if post FRT is higher on average in the underlying population than pre FRT, the null and alternative hypotheses tested were $H_0: \mu(\text{Post}) \leq \mu_{\text{Pre}}$ and $H_1: \mu_{(\text{Post})} > \mu_{\text{Pre}}$ where $\mu_{(\text{Pre})}$ and μ_{Post} respectively denote the pre- and post-population mean FRT score.

Thus, as shown (see table 11), after adjusting for previous experience of Pilates and possible interaction, there is a significant increase in post FRT scores relative to pre FRT scores with time effects ($p < 0.001$). The estimated increase in the FRT score is 27.44-31.59= +4.15. There is statistical evidence that the post-scores exceed the pre-scores, on average, in the population.

For TUG (where a similar one-sided test was employed), there is statistical evidence that the pre-scores exceed the post-scores on average in the population. The TUG

test, which decreased the time score is 7.89-6.93= -0.96. The TUG, the average pre-scores exceeded the post-scores in the population. A significant difference exists between the time effects ($p<0.001$) for the TUG test in which the time score decreased, suggesting an improvement in functional mobility (see fig.21)

For the physical activity questionnaire, the estimated increase in time score in IPAQ (METs) is 3.373-3.994 = +0.621. Multivariate analyses identified an interaction between Time and Pilates effects only for this response IPAQ ($p = 0.017$).

Table 11 Mobility, functional mobility, fear of falling and physical activity means and standard error measurements.

			p-values		
			Main effects		*Interaction*
Response	*Pre-test*	*Post-test*	*p-value for Time*	*p-value for Pilates*	*Time*Pilates*
Functional Reach Test (cm)	27.44 (1.16)	31.59 (0.94)	**p<0.001***	0.504	0.245
Time Up and Go (sec)	7.89 (0.19)	6.93 (0.19)	**p<0.001***	0.686	0.647
FES-16	23.84 (1.64)	22.45 (1.07)	0.345	0.440	0.904
IPAQ (METs)	3.373 (5.82)	3.994 (6.83)	0.478	0.480	**0.017***

Note: values are Mean and Standard error for the pre and post-test. *Values statistically significant ($p\leq0.05$). Abbreviation: Falls efficacy scale (FES-16), IPAQ: Short International Physical Activity Questionnaire; METs: Metabolic Equivalent of Task.

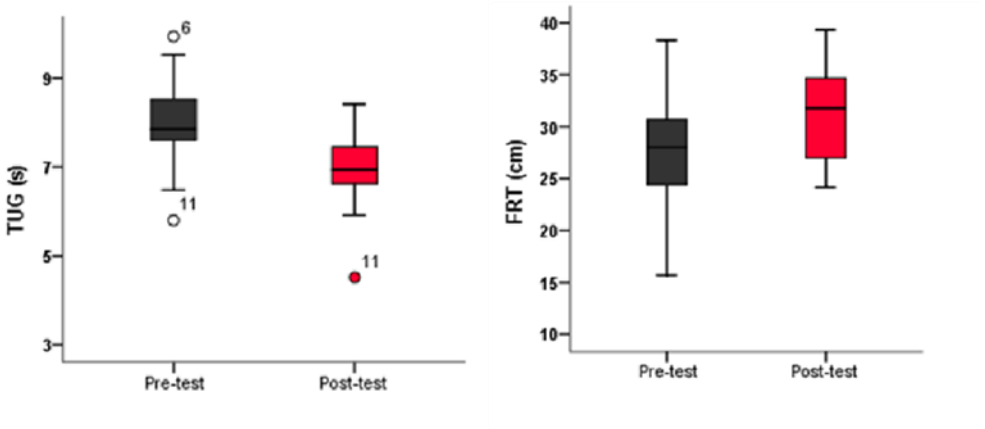

Figure 21 The univariate results for each of TUG and FRT are given as part of the multivariate printout. The graphs shown Figure 20 illustrate stem-and-leaf plots for the variables TUG (which has p-value <0.001) and FRT (p-value <0.001 also). The dark and red bars respectively illustrate the pre- and post-test results.

With regard to gait (see Table 12), an improvement in four variables of gait in the following domains was identified using the univariate components of the output from the multivariate analysis; the effect size of Velocity is 5.65 and the difference is significant in time (p=0.022) (see fig.22). The estimated decrease in the Swing Time score was 0.3790-369=-0.01; this change across time is marginally significant, at least if one uses a 5% level of significance (p=0.049). Stance Time score was 0.643-0.623= -0.02 and this was a significant time effect, (p= 0.013). The univariate results for the Swing Time show statistical evidence of a time effect (since p=0.016). The univariate results for the Double Support Time show a significant time effect (p = 0.040), but there is no evidence for the multivariate analyses. The balance test showed that the static bipedal measure multivariate analysis identified a decrease in time score in the ML direction (see Table 12) and a significant difference between time effects in BIML (p = 0.025), (see fig.22). A significant effect of prior Pilates experience was found only in AP (p-value = 0.037).

Table 12 Balance and Spatiotemporal parameters of gait gives pre and post-test mean and standard error

			p-values		
			Main effects		*Interaction*
Response	*Pre-test*	*Post-test*	*p-value for Time*	*p-value for Pilates*	*Time × Pilates*
Platform/Balance					
BIAP (cm)	5.17 (3.39)	4.96 (2.59)	0.833	0.959	0.824
BIML (cm)	4.61 (7.68)	2.97 (3.67)	**0.025***	0.417	0.367
AP (cm)	6.63 (4.28)	5.09 (5.05)	0.085	**0.037***	0.900
ML (cm)	6.91 (5.18)	6.29 (5.11)	0.071	0.349	0.278
Spatiotemporal Parameters of Gait					
Velocity (cm/s)	136.54 (2.68)	142.19 (2.63)	**0.022***	0.649	0.063
Stride Length (cm)	147.32 (11.70)	141.45 (3.03)	0.342	0.765	0.965
Swing Time (sec)	0.379 (0.08)	0.369 (0.05)	**0.049***	0.305	0.324
Stance Time (sec)	0.643 (0.11)	0.623 (0.10)	**0.013***	0.174	0.382
Double Support Time (sec)	0.269 (0.08)	0.257 (0.07)	0.062	0.335	0.396

Note: values are Mean and Standard error for the pre and post-test. *Values statistically significant (p≤0.05). Abbreviation; BIAP: anteroposterior bipedal; BIML: mediolateral bipedal; AP: anteroposterior (L/R) and ML: mediolateral (L/R) left and Right.

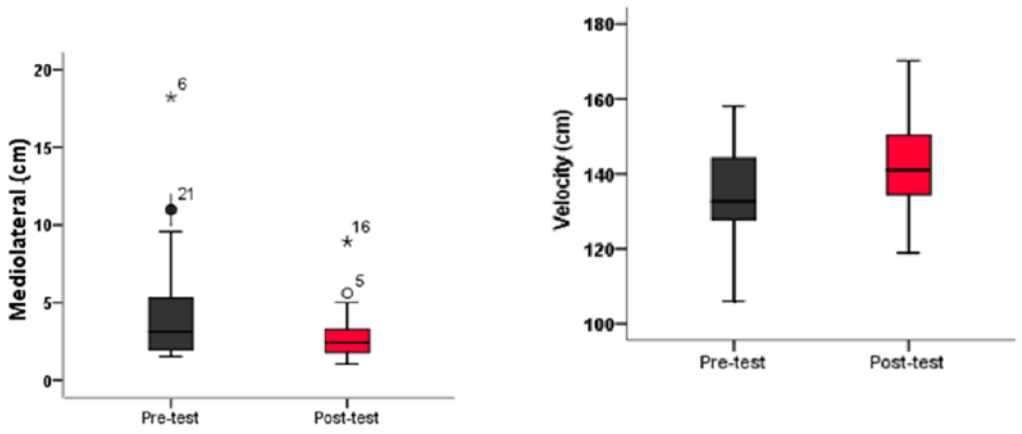

Figure 22 The univariate results for each of mediolateral (BIML) and velocity are given as part of the multivariate printout. The graphs shown Figure 16 illustrate stem-and-leaf plots for the variables BIML (which has $p<0.05$) and velocity ($p<0.05$ also). The dark and red bars respectively illustrate the pre- and post- test results.

4.5 Discussion

For this study, it was hypothesised that there would be functional mobility, mobility, spatiotemporal parameters of gait, postural balance, fear of falling and physical activity changes in healthy older adults after mat Pilates training with supplementary training at home that could decrease the risk of falls. Thus, the 6-week mat Pilates training programme had positive effects on healthy older adults over 65 years of age.

4.5.1 Functional Mobility and Mobility

In this study, healthy subjects showed an improvement of 0.96 sec in functional mobility between pre and post-test. In a similarly sized study (n=27), after five weeks of training, a decrease of 0.90 sec was found. However, Pilates reformer equipment was used (Bird et al., 2012) and after eight weeks, only (n=7) participants did not show improvement in functional mobility (Kaesler et al., 2007). After 12 weeks of intervention with supplementary exercise at home, those doing traditional Pilates with accessories showed a more remarkable improvement in

functional mobility than those in the Pilates equipment group (Josephs et al., 2016). This Mat Pilates study did not include any accessories and an improvement in functional mobility was still evident. It was also observed that TUG was not influenced if the individual was already very active at the point of enrolment into the study. There was however, an improvement in those with prior experience of Pilates in regards to functional mobility, even in those who continued their usual exercise routine during the study.

These findings are similar to the results of Bertoli et al. (2017). Their study involved six weeks of training with 18 participants; an improvement in TUG was found even though most participants did cease their regular exercises (aqua aerobics, gymnastics and walking). There was no comparison of control and experimental groups (Bertoli et al., 2017). Participants who had a history of falls and did not practice Pilates in the previous year (Josephs et al., 2016) may have a more significant improvement in TUG. In older adults without mobility impairment, capacity-related mobility measures are not useful in predicting performance in real life (Giannouli et al., 2016). Our study shows that mat Pilates improve both TUG and FRT.

Previous Pilates studies demonstrated improved mobility for the FRT (Kalron et al., 2017; Pata et al., 2014; and Johnson et al., 2007). This study showed a 4.15-cm increase; Kalron et al. (2017) found a 4.8-cm improvement in the Pilates group over the physiotherapy group (2.6 cm) (Kalron et al., 2017).

4.5.2 Spatiotemporal Parameters of Gait

The six-week intervention was enough to improve the patterns of gait in healthy older adults. Changes in velocity and decrease in swing, stance, double support time as the temporal parameters of gait were identified.

The improvement in velocity showed that participants became more agile and able to move their bodies forward more quickly due to better-controlled movements and improved functional mobility, decreasing their fear of falling. If the opposite happens, it will indicate lack of mobility and propensity to the risk of falling. The literature has documented decreased velocity as a consequence of avoiding falls and a lack of daily activities is associated with fear of falling (Kirkwood et al. 2011). In addition, fear of falling has a powerful effect on gait speed, stride length and double support time among individuals with or without a history of falls (Makino et al., 2017). Older women who have not had recurrent falls, an increase in velocity, cadence and step length and a decrease in swing and stance time were observed (Moreira et al. 2015). These findings are similar to these current findings and the mat Pilates intervention is shown to be useful for improving the temporal parameters of gait that may prevent recurrent falls in healthy older adults.

According to these results, four previous Pilates studies found that individuals walked faster after 8 to 12 weeks of training (Newell et al., 2012; Shea & Moriello 2014; Roh SuYeon et al., 2016; and Kalron et al., 2017); however, different equipment was used to assess the participants in each study. Thus, Roh SuYeon et al. (2016) found improvement in gait velocity had an effect in increase stride length in neurologic participants due to strengthening of the quadriceps, gluteus medius, adductor magnus, gastrocnemius and anterior tibialis also increased range of motion of the lower extremity joints due to greater power in the deep muscles (abdominal) by 3D motion and treadmill equipment used (Roh SuYeon et al., 2016).

Other than an improvement in stride length in subjects with neurological impairment (Shea & Moriello 2014; Roh SuYeon et al., 2016). This study found that stride length was not significantly different after Pilates; however, the decrease in stride length gait parameter may raise the risk of falls in older adults. In addition, a moderate reduction in stride length and a mild fear of falling may compensate for stability while walking in healthy subjects.

It has been stated, within a systematic review, that any intervention, even those that did not aim to improve muscle strength and power, can increase gait speed (Beijersbergen et al., 2013). Moreover, individuals with fear of falling have a lower gait velocity than those with no fear of falling (Reelick et al., 2009). Finally, it remains unclear whether the changes in gait speed, stride length and double support time are caused by a functional impairment or the individuals' effort to adapt their walking to accommodate their fear of falling (Makino et al., 2017).

4.5.3 Postural Stability and Physical Activity

This study demonstrated improvement in mediolateral direction (36%) in open-eye and bipedal conditions. The decrease in mediolateral direction shows an improvement in the control of the center of gravity within the support base (Wall et al., 2009). Thus, older adults become more confident in their daily activities (Wall et al., 2009; Posa et al., 2017). Pilates has been shown to decrease the risk of falls in older adults, improving mediolateral direction due to neuromuscular adaptation (Bird et al., 2012). This Pilates study includes exercises performed in lying and standing positions, which are beneficial in improving balance. This study supports the theory that mat Pilates activates the deep trunk muscles (Hyun et al., 2014) and standing exercises stimulate multisensory function, such as the leg pump, without the use of the hand for support (Barker et al., 2016). Postural stability was the

strategy mechanism to maintain postural control while walking. These findings corroborate the findings of a systematic review that all interventions can improve neuromuscular function and probably increase gait speed, consequently improving balance and sitting posture to stand (Beijersbergen et al., 2013).

This research found that the anteroposterior direction for the single-leg performance was the only variable significant in time effects for the factor Pilates and IPAQ found an interaction between time and Pilates factor. It is interesting to note that those who had previously experienced Pilates before the study design became more physically active after the program and exceeded their scores of METs min/week. Those participants who experienced Pilates however, improved motor learning from repetition. According to Voelcker-Rehage, motor learning can be understood not only as new skills that have not yet been experienced but also as new skills that have already been experienced before, in this case, relearning and improving motor skills acquired in the past (Voelcker-Rehage, 2008). Whilst it was observed that Pilates improved the subjects' neuromuscular function to control postural stability, this research, however, found no significant changes for balance in single-leg standing performance and the Fall Efficacy Scale questionnaire; however, that could be because the intervention was short and the population consisted of more active, healthy, older adults and participants may have a fear of falling. The Pilates training had a positive effect in that no participants reported falls in the study duration.

4.6 Limitations and Advantages

This study was the first Pilates research introduced in Ireland in healthy older adults, there was no prior evidence in Pilates training concerning the exercises explored and how the participants would respond to the Pilates performance. The limitations

of this study were the small sample size, the lack of a control group and lack of a blind assessor and the fact that participants' attendance in the Pilates classes was not recorded. Most of the participants were women; hence gender bias may have influenced the results. The results might be different for people who are sedentary or who have had recurrent falls. The stride length parameter of gait can be a sign of fear of falling. In addition, the clinical tests may have been contaminated by the Hawthorne effect (McCarney et al., 2007) and the potential for learning effects should be considered.

Furthermore, the collection of data did not follow any standard probabilistic design. This can result in bias of the results and for this and other reasons such as the large number of tests performed, relative to the sample size (n=27), the results of the study are exploratory. Statistics can be partitioned into three parts, descriptive statistics, exploratory statistics and inferential statistics. Exploratory statistics falls between the other two in the sense that it describes the sample and seeks hypotheses that could be tested when new data become available. Even though several statistical tests were conducted, the results as are not considered inferential, because these inferences may be incorrect due to the failure of the method of sampling to involve randomness and because when a large number of tests are carried out it is quite possible to get a spurious result (e.g. we might conclude an effect is present even it is not; using a small level of significance helps to some extent in ameliorating this.

4.7 Suggestions

It is recommended that future studies should tackle a larger set of time points at which measurements on each response variable are taken and to introduce other training exercises with which Pilates would be compared. Of course, this will

involve increased sample size but it retains the advantages of repeated measures designs.

With regard to fear of falling and balance, Pilates training should be for a more extended time-period to improve single-leg standing for postural stability and spatiotemporal parameters of gait. In addition, the interaction between gait and stability should be analysed, as well as age, gender, height and health status.

At-home Pilates exercises online and with a booklet are valid for older adults and may help to avoid difficulties such as transportation issues in physically attending Pilates classes. The Pilates program may play a role in reducing the risk of falls in older adults in the community and may promote health and well-being.

4.8 Conclusion

The results support the theory that a six-week traditional mat Pilates program supplemented with a booklet of home-based exercises is effective for reducing the risk of falls by improving the outcomes of known risk factors for falls. However, high-quality clinical trials with larger sample sizes are needed to confirm this finding. The implications of these findings for a frailer population may be different, so further research is required to clarify and ascertain whether mat Pilates can help prevent falls and decrease mortality and morbidity. The advantage of Pilates is that it is readily available and accessible to community-dwelling older adults. Pilates is low in cost and can contribute to the improvement of functional mobility, mobility, mediolateral direction for postural control and the spatiotemporal parameters of gait (velocity, swing, double support and stance time). Physical activity has a significant impact on postural stability in healthy older adults. The risk factors for falls may be

reduced and may provide consequent savings in health and social care for the older adult population.

4.9 Clinical Relevance

- Six weeks of Pilates improved postural control thus reducing falls risk as observed by a decrease in mediolateral sway.
- The temporal parameters of gait were shown to improve even in healthy older adults with good levels of functional mobility at enrolment.
- Physical activity had a significant impact on balance improvement.
- There were no changes regarding fear of falling in healthy older adults after six weeks of Pilates.

4.10 The cohort study informs the RCT

The cohort study indicated the randomised clinical trial (RCT) study regarding to the exercises will be evaluate for a longer period of 12 weeks intervention. After six weeks of the intervention, the participants became more familiar with the exercises. After that period, it will be possible to include the use of Pilates accessories, enabling the participants to advance their level when exercising. The exercises will be focused on standing position performance exercises to improve gait and balance.

Regarding balance assessments, participants will perform with eyes open and closed conditions, and the time will be recorded for thirty seconds each. Therefore, the postural balance (performance in the bipedal standing position to single leg standing position) test was revised. Postural balance will be recorded for 30 seconds rather than 10 seconds. Some previous Pilates studies have assessed postural

balance in the standing position for 10 seconds on each leg (Donath et al., 2015) or for 20 seconds (Newell et al., 2012), whereas most studies assess postural balance for 30 seconds (Kaesler et al., 2007; Bird et al., 2012; Markovic et al., 2015; Mesquita et al., 2015; Vieira et al., 2017). This suggests that 30 seconds is the most reliable duration for clinical diagnosis. Lafond et al. (2004) demonstrated an increase in the reliability of CoP measures, such as an increase in the trial duration, recorded in healthy older adults over 60 years. Further, the spatiotemporal parameters o gait will be included such as Cadence (Step/Min), Velocity (cm/s), Stride Length (cm), Step Length (cm) and Step Time (s). All measures explained in discussion section of chapter 5.

The RCT will be confirmed in terms of the outcomes measures and results. Furthermore, a survey of Pilates exercises will be draw to the participants to answer the question in the day of the assessments after twelve weeks of intervention.

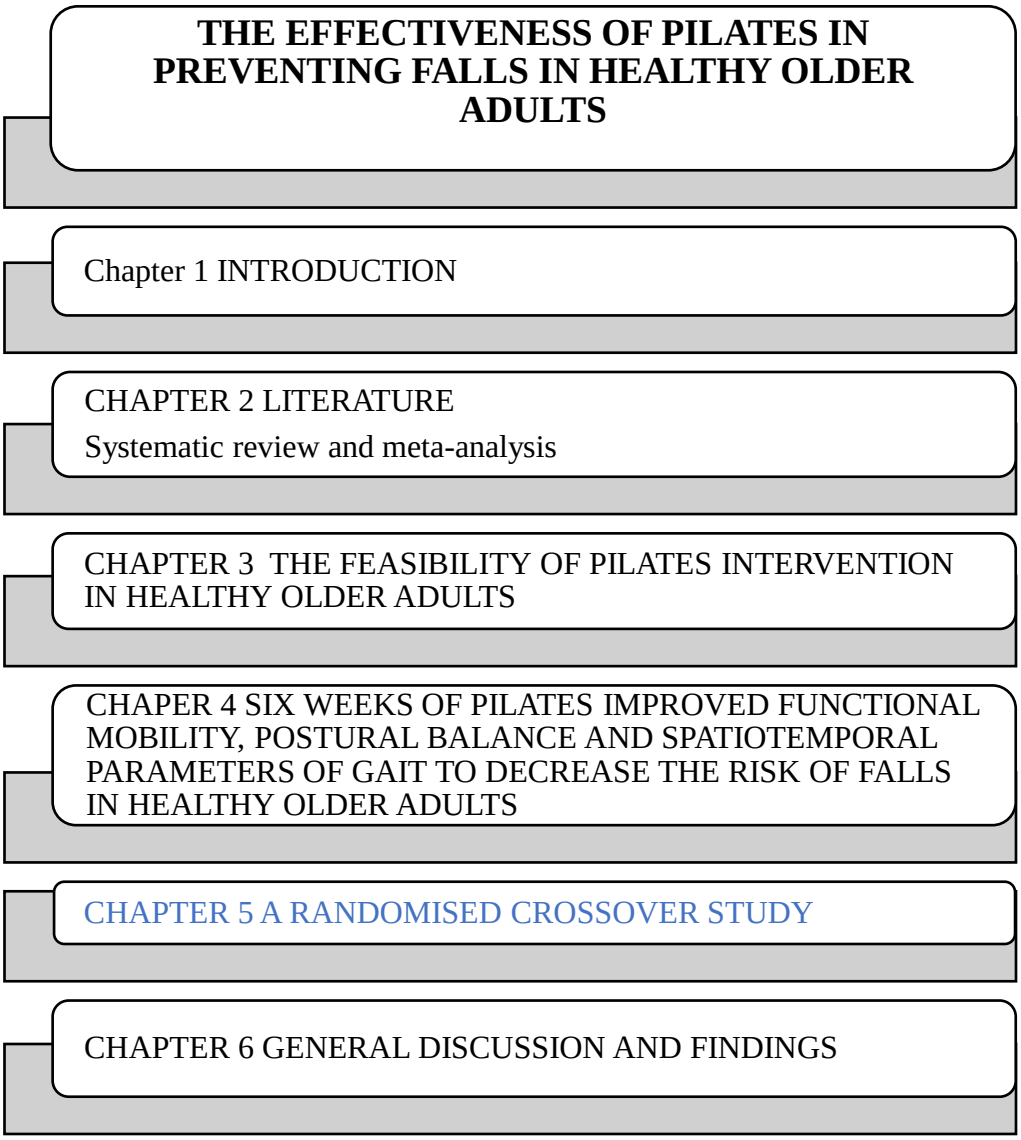

Figure 23 Layout of the thesis

CHAPTER 5: A RANDOMISED CROSSOVER STUDY

Abstract

Background: This is the main study contained in this thesis, which investigates the effects of a 12-week mat Pilates exercise with accessories and a supplementary home-based exercise and control group with no activity on reducing falls in a group of healthy adults aged ≥ 65 years.

Methods: The study used a randomised crossover design implemented during a seven-month period with a one-month washout period. The volunteer subjects (n = 61) were randomly assigned to Group 1 (Control-Pilates) or Group 2 (Pilates-Control). Primary outcome measures: spatiotemporal parameters: velocity (m/s); centre of pressure (CoP) of postural stability: mediolateral (cm) and anteroposterior (cm) sway; and fear of falling. Secondary outcome measures: spatiotemporal parameters: cadence (step/min), stride length (cm), step length (cm), step time (s), swing time (s), stance time (s), double support time (s); functional mobility; mobility; and physical activity. Further, participants were asked to record a fall if occurred during the study. GEE was used to analyse the time, groups and interaction effects.

Results: Time Up and Go (TUG) and mediolateral (ML) directions of balance showed statistical significance in time effects ($p < 0.05$). The gait parameters following cadence, (stance, step and double support time) showed statistical significance in time effects ($p < 0.05$) and significant differences between the two groups ($p < 0.05$). Further, an interaction between time and groups was found for FRT ($p < 0.001$).

Conclusion: Effects of 12 weeks of Pilates intervention on functional mobility, mobility, postural balance and spatiotemporal gait parameters were identified. The 28 weeks of intervention programme showed that participants did not have a fall when they were into a Pilates group. Further trials of a longer duration are warranted to determine the effectiveness of Pilates on falls prevention.

Key-words: Pilates, elderly, fall prevention

5.1 Introduction

Age-related loss of skeletal muscle mass (Tieland et al., 2018), muscle strength or muscle power are frequently observed in older adults and are known to cause limitations in daily mobility and functional capacity (Grimmer et al, 2019). Furthermore, these age-related degenerative changes can impact upon quality of life and physical performance in older adults (Tieland et al., 2018). Advancing age is associated with decreased balance control (Roman-Liu, 2018) as well as deterioration of motor skills, which affects walking ability (Pirker & Katzenschlager, 2017), functional capacity for ability and intensity movements for daily tasks such as walking and climbing stairs (Grimmer et al, 2019). Finally, decreased balance may cause fear of falling, which leads to changes in gait patterns among the older adult population (Verghese et al., 2009; Donoghue et al., 2013; Donath et al., 2014).

A fall is a complicated event that can have implications on a person's wellbeing particularly in the domains of their physical health, mental health and social wellbeing, therefore, a focus on the prevention of falls is crucial (Pin and Spini 2016). A fall occurs when a person has difficulty maintaining their center of gravity (COG) within the base of support by their feet (Roman-Liu, 2018). Most dangerous falls happen when older adults are walking, thus the spatiotemporal parameters of gait are useful for assessing individuals in a clinical setting to identify which older adults are at risk of falls (Mortaza et al., 2014). To establish falls risk Public Health England and the National Falls Prevention Coordination's (2019) recent recommendations include using tests such as Time Up and Go, the 30 second chair rise and the Short-Form Falls Efficacy Scale-International (FES-I) and recording any falls during the previous 12 months. Furthermore, they also recommend a 12-

week follow-up exercise program (whereby the attendance of the participants in class should be more than 75%).

Exercise programs have been found to be effective in reducing the risk and rate of falls (Chang et al., 2004). A recent systematic review and meta -analysis stated that the rate of falls reduced by 39% after exercise balance programs (Sherrington et al, 2017).

Public Health England and The National Falls Prevention Coordination (2019) have recommended that exercises should focus on balance training and must be challenging, including movements that encourage working the center of mass, forming a smaller base of support and decreasing upper limb support. Including a supplementary home-based exercise (Sherrington et al, 2017). Exercises with such equipment focused on the lower limbs, core and trunk.

The Physical Activity Guidelines Advisory Committee Report (2008) recommends that people aged 65 years and older should perform moderate intensity aerobic, muscle-strengthening and balance activities for 30 minutes a day, five days per week, or at least 150 minutes per week.

Pilates exercises are useful to help older adults improve their mobility and independence and to decrease the burden of falls. A recent systematic review on the effect of Pilates method on physical fitness in the elderly concluded that there is a need for high quality clinical trials with greater methodological rigor. Specifically, trials that report on under investigated variables including the specific exercises that were performed, intensity, number of repetitions, number of absences and training of the Pilates professional (Pucci et al. 2019). A recent Pilates (RCT) study found improvement in balance confidence, fear of falling and postural stability in older women after twelve weeks of training (Aibar-Almazan et al.,

2019). However, in contrast to that, three studies found no improvement in balance for the Pilates groups after eight weeks (Donath et al., 2016) and twelve weeks of training respectively (Gabizon et al., 2016) and a crossover study found no difference between groups of Pilates and control (Bird et al., 2012).

Previous studies on Pilates have shown efficacy in both the short and long term in decreasing the risk of falls. However, there is still a shortage of studies that evaluate the fear of falling, spatiotemporal parameters of gait and after effects of a Pilates intervention program with supplementary home-based exercise. Thus, this randomized crossover study investigated whether a 12-week Pilates intervention with a supplementary at-home program was effective in reducing the risk of falls in healthy older adults (≥ 65 years).

5.2 Aims

The aim of the study was to identify whether fear of falling, physical activity, postural balance, functional mobility, mobility and spatiotemporal gait parameters were affected after completion of a 12-week intervention programme. A further aim was to determine if Pilates is effective in decreasing the risk of falls in healthy adults aged ≥ 65 years of a seven-month programme.

5.3 Research questions

- Does Pilates with accessories training of twelve-week programme duration effectively improve postural stability, mobility, functional mobility, physical activity, the fear of falling and the spatiotemporal parameters of gait?
- Is Pilates intervention of seven months period effective in decreasing falls in healthy adults aged ≥ 65 years?

5.4 Objectives

- To evaluate postural stability, mobility, functional mobility, physical activity, the fear of falling and the spatiotemporal parameters of gait after a 12-week Pilates training programme.
- To determine if Pilates intervention is effective in decreasing the risk of falls experienced by participants during the seven months programme.

5.5 Hypotheses

Pilates with accessories training programme of twelve weeks will improve healthy older adults in the following parameters: functional mobility, mobility, fear of falling, physical activity, postural balance for the center of pressure (CoP) parameters of mediolateral and anteroposterior directions and the spatiotemporal parameters of gait such as cadence (step/min), velocity(cm/s), step length (cm), stride length (cm), step time (s), swing time (s), stance time (s) and double support time (s). Pilates intervention will investigate whether the twelve weeks period of intervention during a seven-month programme will be effective in reducing falls in healthy adults ≥ 65 years old.

5.6 Methodology

5.6.1 Study Design

This study is a prospective, open label crossover trial design that was implemented during a seven-month period with a one-month washout period (no activity) programme. Participants were assigned to the 12-week intervention initially. After the one-month washout period, the groups were crossed over and participants were assigned either to a Pilate's intervention group or control group. This study

followed the *CONSORT 2010* guidelines with regard to extension to randomised crossover trials (Dwan et al., 2019).

5.6.2 Recruitment

Study enrolment was completed in two stages. Firstly, recruitment took place in January 2017; meetings were held for those interested in participating in February 2017 and participants were allocated to the assessments in May, September and December 2017. Secondly, additional participants were recruited in October 2017 (see fig. 25 on participants section below); these participants were allocated to the assessments in November 2017 and March and July 2018.

The assessor conducted the assessments at, test 1 (T1) before intervention and post-test 2 (T2) after the 12-week programme; the test 3 (T3) was conducted after the washout of four weeks and completion of the twelve weeks programme (28 weeks of the overall study timeline) (See figure 24 below). The participants were assigned randomly to group 1 or group 2. The group 1, participants started with no activity for 12 weeks and after the four weeks washout period, the participants were crossover and allocated into Pilate's exercise for 12 weeks: C-P (control (C) and Pilates (P)). The participants were assigned into group 2, participants started with Pilate's exercise for 12 weeks and after the four weeks washout period, the participants were crossover and allocated into control with no activity for 12 weeks: P-C (Pilates (P) and control (C)).

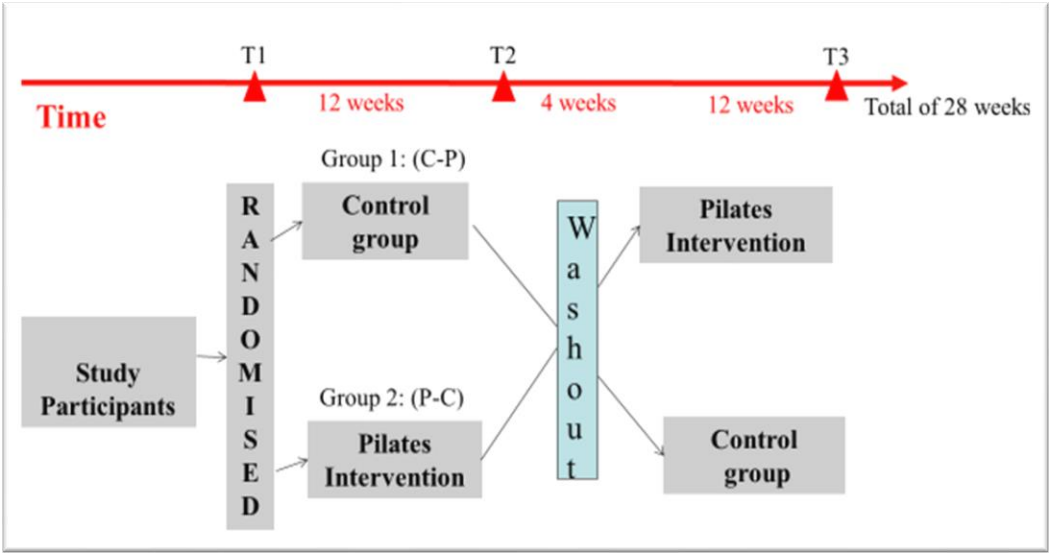

Figure 24 Randomised Crossover Study Diagram

The study was advertised on the internet, in local newspapers and on the radio. The study information was also disseminated among the following retirement communities in Galway: Renmore, City Centre, Newcastle and Salthill. The principal investigator (PI) was also invited to publish an article in local newspapers about the study including in the Galway Advertiser (Appendix 11). The PI held meetings with those interested in participating at the National University of Ireland (NUI) Galway. The PI provided an information sheet to the volunteers (Appendix 3). All the interested volunteers signed an informed consent form before the study began. The study was approved by the NUI Galway Research Ethics Committee (REC)-NUI Galway Ref 15/May/02 (Appendix 2).

5.6.3 Randomisation

A binary simple randomised list was used (https://www.random.org/sequences/) to allocate the participants to two different groups: 1 (C-P) and 2 (P-C) without stratification; this was an open label clinical trial and no blinding of assessors and

participants was performed. Allocation concealment was performed using a sequential number list – each number corresponded to a particular participant to indicate which group the participant would be allocated in. The PI enrolled and assessed participants sequentially.

After participants completed the screening assessments the allocation of participants for the groups was revealed. The participants were assigned randomly to group 1 or group 2 (the control group were not to engage in any additional exercise above their usual daily activities).

5.6.4 Participants

Inclusion criteria: healthy older adults ≥ 65 able to attend the Pilates sessions regularly who had not undergone surgery in the past six months and had no restrictions placed on them by their general practitioners. Exclusion criteria: a Montreal Cognitive Assessment (MOCA) score < 26 (Nasreddine et al., 2005), had chronic musculoskeletal pain (e.g., chronic back pain) (Barker et al., 2016), had acute inflammation (injury of the knee, hip, or shoulder, such as tendinitis), had an illness (e.g., unstable blood pressure, myocardial infarction) that could limit their ability to perform exercises safely (Barker et al., 2016), had a history of neurological impairment, had medical and pharmacologic contraindications to exercise, vertigo or had a vigorous exercise routine already.

In total, 99 people were assessed for eligibility and 61 healthy older adults were eligible to participate in the study and randomised to group 1: C-P (n = 29) and group 2: P-C (n = 32). After participants were allocated to the groups, serious adverse events occurred and the reasons for loss to follow-up included sickness (n = 3), surgery (n = 2), became ill (n = 1), no reason (n = 2) and lack of time (n = 4).

In the control group (group 1), n = 1 dropped out as a consequence of a fall. This participant had been injured and could not continue.

After the crossover, the participants were allocated into group 1 (n = 31) and group 2 (n = 17). Further adverse events: participants who were lost to follow-up or discontinued intervention (n = 2) due to joint discomfort (n = 2), heart disease (n = 1), became ill (n = 1) or went on a holiday (n = 2). At the end of the seven months programme, the groups finished the trial with the following numbers of participants: group 1 (n = 23) and group 2 (n = 17) (see Figure 25).

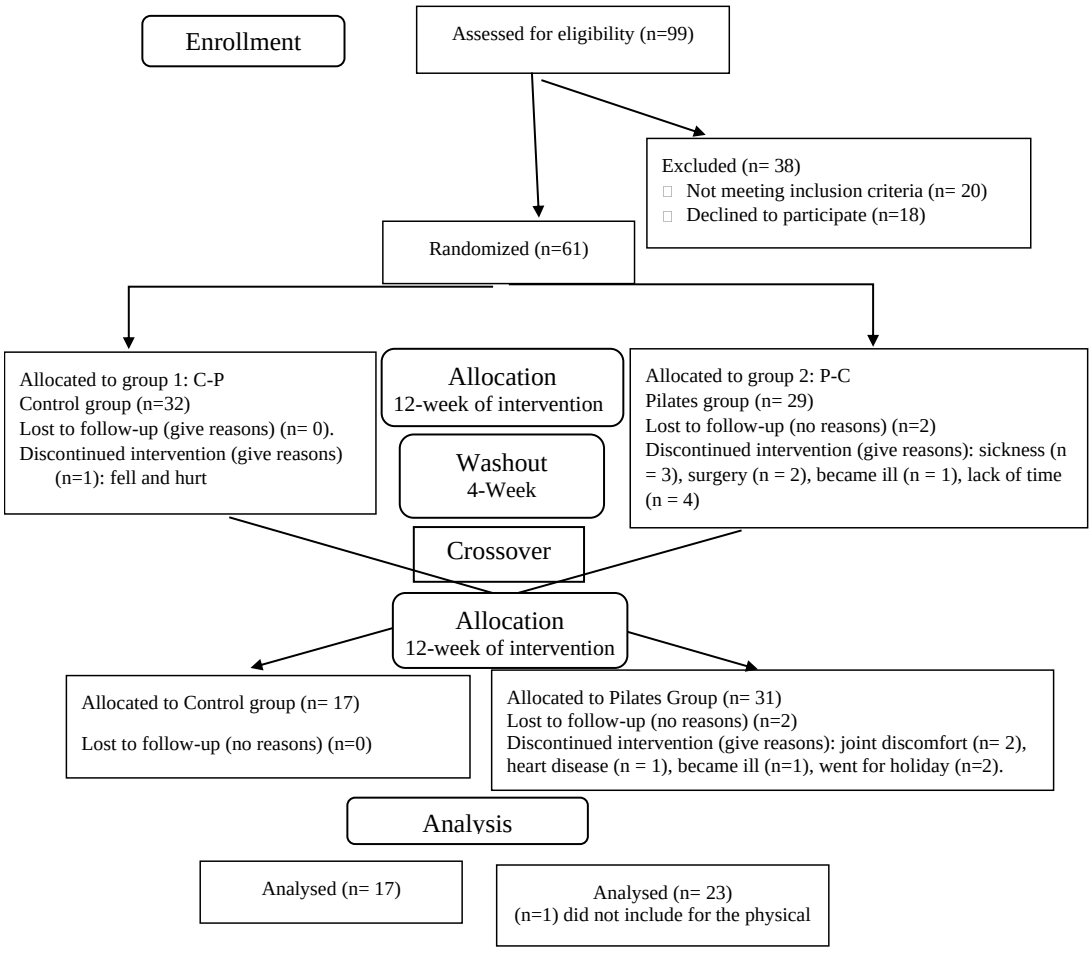

Figure 25 Participants

The characteristic details of the participants at baseline are presented as mean (SD): age = 69.79 (5.21), height (cm) = 163.69 (7.81), BMI (kg/m^2) = 25.86 (3.62),

MOCA = 27.37 (1.30). The health status including participants who had (joint replacement (n = 2), muscle discomfort (n = 5) past surgery (n = 6). Total of participants health status were 21.3%. Further, falls in the past year (12 [19.7%]), fear of falling (15 [24.6%]). There was no significant difference between groups ($p > 0.05$) (see Table 13).

Table 13 Baseline characteristics of participants between groups

Variables	*All participants (n=61)*	*P-C (n=29)*	*C-P (n=32)*	*p-value*
Age	69.79 (5.21)	68.82 (3.98)	70.65 (6.06)	0.260
Gender *n* (%) M=male F=female	M=14 (23%) F=47 (77%)	M=8 (27.6%) F=21 (72.4%)	M=6 (18.8%) F=26 (81.3%)	0.412
Height (cm)	163.69 (7.81)	164.48 (6.84)	162.96 (8.64)	0.251
BMI (kg/m^2)	25.86 (3.62)	26.57 (4.17)	25.23 (2.97)	0.151
MOCA	27.37 (1.30)	27.65 (1.4)	27.12 (1.15)	0.114
Health Status *n* (%)	13 (21.3%)	6 (20.7%)	7 (21.9%)	0.910
Falls in the past year *n* (%)	12 (19.7%)	5 (17.2%)	7 (21.9%)	0.649
Fear of falling *n* (%)	15 (24.6%)	5 (17.2%)	10 (31.3%)	0.204

Note: Mean (SD) or n (%) for variables. No significant difference between groups of Pilates and Control ($p > 0.05$). Abbreviation: Montreal cognitive test (MOCA), Body Mass Index (BMI). Group 1 (C-P) Group 2 (P-C)

5.6.5 Instructor of Pilates

The principal investigator (PI), who was in charge of teaching the participants, as a physiotherapist (2005) had a thorough understanding of the exercise protocol that was specifically designed for older adults. The Pilates instructor undertook a Pilates training course at Body Control Pilates-London (2015) and clinical mat Pilates through International Valeria Figueiredo's course (an Australian Instructor) in Brazil (2008).

5.6.6 Pilates intervention

The Pilates intervention was a clearly defined study protocol. The Pilates intervention took place at the Áras Moyola building, NUI Galway.

Supervised exercises: The supervised Pilates classes took place twice a week for one hour for a total of 12 weeks. There was a maximum of ten participants included

in each group, led by a qualified Physiotherapist and Instructor of Pilates. The classes were divided into a warm-up, standing position exercises (including squats and walking), mat Pilates with accessories and a cool-down. The mat exercises involved workouts in sets of two to three and repetitions of ten. The supervised exercises were evaluated every three weeks for frequency, repetition and the inclusion of small equipment in each exercise (See Table 14 and 15 below).

Table 14 Accessories according to the exercises included

Small Equipment	**Mini band: yellow, blue and green**	**Long band: blue and purple**	**Spiky Ball**	**Ring**	**Blocks**	**Foam Roller**
Exercises	Walking squat	Single leg stretch	Squat	Traditional Squat	Bridge	Coordinator (leg and arm lifts)
	Bicycle	Plantar flexion	Leg raises	Breathing (arms)	Forearms support	Lying back on the roller (rolling forwards and backwards)
	Leg sweep front to back	Double leg stretch	Walking	Bridge		Spine forwards
	Oyster	Spine forwards		The hundred		
	Single leg kick					
	Inner thigh lift					

5.6.6.4 Home-based exercises:

The participants were asked to perform supplementary at-home workouts three times a week for 30 minutes using a booklet and video that were provided. The video and booklet introduced the six principles of Pilates, including centering, control, concentration, flow, precision and breathing (Kloubec, 2011) in a warm-up, exercises with a chair, traditional mat Pilates and cool-down exercises (see appendix 12).

The video and booklet were designed by the Pilates instructor. The booklet contains pictures of exercises demonstrated by the instructor. Participants also had access to a home-based Pilates exercises video via a Dropbox link sent to their emails by the Pilates instructor. The instructor also explained and demonstrated the at-home exercises in the video to the participants during the first supervised Pilates class. Participants were also asked to keep falls diaries and give feedback notes and comments. The participants were asked to give feedback on the same day as the assessments (post-test).

Table 15: Evaluation of 12 weeks of Mat Pilates program with small equipment

12-WEEK PILATES PROGRAMME				
EXERCISES EACH 3 WEEKS				
Weeks	**1-3**	**4-6**	**7-9**	**10-12**
Accessories	Ring/Band	Ring/Band/Spiky ball	Ring/Band/Mini band/Spiky ball/Foam roller/Block	Ring/Band/Mini band/Spiky ball/Foam roller/Block
Warm Up	Standing position: 1) Breathing with ring (held in hands 10 times) 2) Leg pumping with ring (held in hands 2×10)			
Standing Position	• Squat with ring (hands) 2x5	• Squat with ring (hands) 2×5 • Walking squat side to side 10 steps • Walking over the spiky ball side to side 10 steps and single leg up	• Squat with ring (hands) 2×5 • Walking squat side to side 10 steps • Walking over the ball side to side 10 step and single leg up in front • Squat with foot on the spiky ball (toes on the floor) 5× • Squat with forward lunge with mini band 5×	• Squat with ring (hands) with the band over the knee and under the knee 2×5 • Walking squat side to side with mini band 10 steps • Squat with forward lunge with mini band 5× • Single leg up in front over spiky ball 10 steps • Squat with foot on the spiky ball (toes on the floor) 5×
Mat Pilates Exercise	• Single leg stretching 3×30 sec • Bridge 3×10 sec with ring • The hundred 3×10 • Coordinator (single leg stretching → knee and ankle) 3×10 • Bicycle forwards and backwards 1 min • Leg sweeps front to back 2×10 • Oyster 2×10 • Inner thigh lift 2×10 • Single leg kick 2×10	• Single leg stretching 3×30 sec • Bridge 30 sec with ring (at 6 week) • Bridge leg stretch up (spine curl) (at 6 week) 5 × • The hundred (double leg up with bench knee) with the ring 3×10 • Coordinator (single leg stretching → knee and ankle) 3×10 • Oblique ankle reaches 3×10 • Bicycle forwards and backwards 1 min	• Single leg stretching 3×30 sec • Bridge 30 sec with ring • Bridge leg stretch up 5× (spine curl) • The hundred (double leg stretch up) with ring 3×10 • Oblique ankle reaches 3×10 • Bicycle forwards and backwards 1 min • Leg sweeps front to back 2×10 • Oyster 2×10 • Inner thigh lift 2×10 • Single leg kick 2×10	• Single leg stretching 3×30 sec • Bridge 30 sec with ring • Bridge leg stretch up 5× (spine curl) • The hundred (double leg stretch up) with ring 3×10 • Oblique ankle reaches 3×10 • Bicycle forwards and backwards 1 min • Leg sweeps front to back 2×10 • Oyster 2×10 • Inner thigh lifts 2×10 • Single leg kick 2×10

	• Supporting on the forearms 3×5 sec • Rocking or Spine-Saw stretching 3×	• Leg sweeps front to back 2×10 • Oyster 2×10 • Inner thigh lift 2×10 • Single leg kick 2×10 • Leg in front stretch with band 3×10 • Plantar flexion with band 3×10 sitting (at 5 week) • Double leg stretching with band and rolling like a ball (3×) and leg stretching while sitting (at 5 week) • Supporting on the forearms 3×5 sec • Rocking or Spine-Saw stretching 3×	• Coordinator with foam roller (leg raises) 10 times per side • Lying back on the roller (rolling forwards and backwards) 5× • Sitting on the roller and stretching 1×30 sec • Leg in front stretch with band 3×10 • Plantar flexion with band 3×10 sitting • Double leg stretching with band and rolling like a ball (3×) and leg stretching while sitting • Supporting on the forearms 3×5 sec • Rocking or Spine-Saw stretching 3×	• Coordinator with foam roller (leg and arm raises) 10 times per side • Lying back on the roller (rolling forwards and backwards) 5× • Sitting on the roller and stretching 1×30 sec • Leg in front stretch with band 3×10 • Plantar flexion with band 3×10 sitting • Double leg stretching with band and rolling like a ball (3×) and leg stretching while sitting • Supporting on the forearms 3×5 sec • Rocking or Spine-Saw stretching 3×
Cool-down	1) Single leg stretching (sitting) 1×30 sec, 2) Bent knee hamstring stretch 1×30 sec, 3) Hip roll (one on each side), 4) Rolling trunk forwards 2 times, 5) Shoulder rolling, 6) Arm stretches 30 sec, 7) Stretching the neck, each side 30 sec, 8) Stretching the calf 1×30 sec, 9) Side lung abductor 1×30 sec			

5.6.7 Control group (CG)

CG participants were recommended to continue their usual routine for twelve weeks. The participants were provided with a falls diary to record their falls. If falls occurred, the participants could get in touch by e-mail and phone call to the PI at any time.

5.6.8 Outcome measures

Primary outcome measures comprised a) spatiotemporal parameters: velocity (m/s); b) centre of pressure (CoP) of postural stability: mediolateral (cm) and anteroposterior (cm) sway; and c) fear of falling.

Secondary outcome measures comprised a) spatiotemporal parameters: cadence (step/min), stride length (cm), step length (cm), step time (s), swing time (s), stance

time (s), double support time (s); b) functional mobility (s); c) mobility (cm); and d) physical activity (METs).

The participants received instructions for the location and the schedule of assessments at the Podiatry Laboratory at Áras Moyola, NUI Galway.

The MOCA – a screening test of global cognitive function – was administered to the participants (Nasreddine et al., 2005). The participants' baseline of demographic details including age, gender, cognitive ability, height (cm) and BMI (kg/m^2); health status as (surgery, replacement and pain); Information about falls was collected by asking the following: 'Have you fallen over in the past twelve months?' Fear of falling was measured by asking, 'Are you afraid of falling over?' At least one fall for (fallers) was counted or no fallers and a minimum fear of falling were considered the baseline details (See in Appendix 8). Demographic details were collected on different days (the same day as the assessments).

Participants received a diary to record their falls at the beginning of the study. During the study period, participants in the PG group reported if they had falls during the Pilates intervention to the PI and participants of the CG recorded if they had any falls in their fall diaries. A survey of Pilates questions was provided to the participants at the end of the Pilates intervention.

Each participant was interviewed using questionnaires to assess their concerns about their fear of falling and their level of physical activity.

The Falls Efficacy Scale (FES- 16-item) (Yardley et al., 2005) (Cited on chapter 4).

The International Physical Activity Questionnaire (IPAQ-short) (Craig et al., 2003) (Cited on chapter 4). The IPAQ data were added in the tool was included to collate data using Excel, which can easily be entered into SPSS (Cheng, 2016).

The Time Up and Go (TUG) test (Shumway-Cook, 2000) (Cited on chapter 3).

The Functional Reach test (FRT) test (Duncan et al., 1990) (Cited on chapter 3).

The Footwork Pro pressure platform (Franklin, New Jersey, USA) (Cited on chapter 3). Stabilometric parameters calculated the centre of pressure (CoP) in anteroposterior and mediolateral AP-ML (cm) sway were recorded.

The GAITRite® (Cited in chapter 3). The following variables were used to predict falls: cadence (step/min), velocity (m/sec), stride length (cm), step length (cm), step time (sec), swing time (sec), stance time (sec) and double support time (sec).

5.7 Statistical analysis

The data are presented as Means and Standard Deviations (SD), frequencies or percentages of the characteristic details for the baseline, test 1 for all variables and participants analysed between groups (group 1/ group 2) was conducted using the Mann–Whitney U test to analyse continuous data (age, height [cm], BMI [kg/m^2] and cognitive ability). A Pearson's chi-square test was performed to examine the categorical variables for gender, health status, fall in the past year and fear of falling (significant at $p > 0.05$). Participants' right legs were considered when measuring postural balance and the spatiotemporal parameters of gait. Participants were asked which side they would like to kick a ball. The total of participants of 91.7% of the answered right side.

The Kolmogorov–Smirnov test was carried out to measure the homogeneity of variance. The data were not normally distributed and non-parametric testing was conducted. Data were presented as mean and 95% confidence interval. Generalised Estimation Equations (GEE). Bonferroni *post hoc* were used to correct the data. The effects were estimated for time (pre-test, 12 weeks and 28 weeks), groups and

time × group interactions. The data were analysed using the Statistical Package for the Social Sciences (SPSS) version 25. Significance was set at p = 0.05.

The power (1-β) and family (F) effect size were calculated using G*Power software (version 3.1; Universität Düsseldorf, Germany) for each variable with the number of participants between the groups.

5.8 Results

5.8.1 Demographic details

Data on the group 1 (n = 17) and group 2 (n = 31) participants were analysed (see Table 2). Demographic data for group 2 included: age between 65–87 years and a higher percentage of females (83.9%) than males (16.1%); six participants reported health status (19.4%) such as (surgery; n=3, replacement; n=2 and pain; n=2), which was more than in group 1 (5.9% or one participant). In group 1, individuals were younger than in group 2 (aged between 65–79 years) and there was also a higher percentage of females (76.5%) than males (23.5%). Following factors of age (p=0.349), gender (p=0.530), height (cm) (p=0.266), BMI (kg/m2) (p=0.444), MOCA (p=0.095) and health status (p=0.206). There were no significance differences between the control and Pilates groups for demographic details (p > 0.05).

However, the variables of cadence (p= 0.042), step time (p=0.027), stance time (p= 0.028), and double support time (p= 0.042), were statistically significant between groups (p < 0.05) (See table 16 below).

5.8.2 Falls details

Participants were asked if they had fallen in the past 12 months. In total, n (%) =12 (25%) participants had fallen over in the previous year. Data was compared between the Pilates group, 3 (17.3%) and the control group, 9 (29%). There were no significant differences between the control and Pilates groups for falls in the past year ($p = 0.384$).

Recurrent falls during the seven-month intervention programme occurred in a total of 7 (14.6%) participants, these participants were allocated to the control group at different time points. Specifically, five participants (16.1%) fell before the crossover and two participants (11.8%) fell after the Pilates intervention and when the groups were crossed over. Those participants were allocated into control group before the groups crossed.

Table 16 All participants characteristics analyses

Variables	*All participants (n=48)*	*P-C (n=17)*	*C-P (n=31)*	*p-value*
Age	70.08 (5.51) 65-87 years	68.88 (4.02) 65-79 years	70.74 (6.14) 65-87 years	0.349
Gender *n* (%) M=male F=female	M=9 (18.8%) F=39 (81.3%)	M=4 (23.5%) F=13 (76.5%)	M=5 (16.1%) F=26 (83.9%)	0.530
Height (cm)	163.26 (8.06)	164.67 (7.59)	162.48 (8.33)	0.266
BMI (kg/m^2)	25.49 (3.21)	25.97 (3.58)	25.23 (3.02)	0.444
MOCA	27.39 (1.26)	27.82 (1.38)	27.16 (1.15)	0.095
Health Status *n* (%)	7 (14.6%)	1 (5.9%)	6 (19.4%)	0.206
Falls in the past year *n* (%)	12 (25%)	3 (17.3%)	9 (29%)	0.384
Fear of falling *n* (%)	17 (35.4%)	5 (29.4%)	12 (38.7%)	0.519
TUG (s)	7.70 (0.87)	7.79 (0.93)	7.65 (0.84)	0.568
FRT (cm)	27.33 (6.01)	27.23 (5.09)	27.38 (6.55)	0.651
FES-16	20.87 (7.71)	19.47 (3.18)	21.64 (9.27)	0.793
IPAQ (MET)	2.948 (2.449)	2.177 (1.551)	2.675 (2.188)	0.457
AP (EO) cm	8.04 (3.67)	8.09 (3.31)	8.02 (3.91)	0.755
ML (EO) cm	4.11 (1.0)	4.09 (0.66)	4.12 (1.16)	0.953
AP (EC) cm	12.46 (6.62)	11.57 (3.50)	12.97 (7.88)	0.947
ML (EC) cm	6.74 (6.40)	6.02 (4.14)	7.14 (7.37)	0.368
Cadence (Step/Min)	120.40 (8.25)	117.50 (7.57)	122.00 (8.29)	**0.042***
Velocity (cm/s)	143.17 (17.80)	138.86 (16.05)	145.54 (18.51)	0.253
Stride Length (cm)	142.42 (12.13)	141.85 (10.07)	142.76 (13.35)	0.964
Step Length (cm)	71.21 (6.60)	70.63 (5.58)	71.53 (7.17)	0.796
Step Time (s)	0.501 (0.037)	0.51 (0.03)	0.49 (0.04)	**0.027***
Swing Time (s)	0.375 (0.024)	0.38 (0.02)	0.37 (0.02)	0.219
Stance Time (s)	0.626 (0.051)	0.64 (0.04)	0.61 (0.05)	**0.028***
Double Sup Time (s)	0.260 (0.042)	0.27 (0.04)	0.25 (0.03)	**0.042***

Note: Mean (SD) or *n* (%) for variables. Statistically significant difference between Group 1 (C-P) Group 2 (P-C) ($p < 0.05$). Abbreviation: Montreal cognitive test (MOCA), Body Mass Index (BMI). Functional Reach test (FRT), Time Up and Go (TUG), Falls efficacy scale (FES-16), IPAQ: Short International Physical Activity Questionnaire; METs: Metabolic Equivalent of Task. AP: anteroposterior; ML: mediolateral. Eyes open (EO), eyes closed (EC).

5.8.3 Pilates

In total, the physical activity level for most of the participants was moderate (21 [44.7%]) to high (18 [38.3%]). The total number (pre- and after crossover) of participants who attended the Pilates classes during the 12-week programme was n = 40 (83.3%). The participants attended an average of 22 Pilates classes (the minimum number to attend was 12 and the maximum was 24).

90% participants felt they needed more than 24 sessions of Pilates exercises and 10% of participants said that 12 weeks was sufficient. The exercises performed in class, stretching was one of the most difficult for the older adults (42.5%) because

their range of motion was limited, followed by cycling backwards (22.5%) and the hundred (10%).

With regard to the frequency of the exercises, most of the participants (72.5%) practiced the home-based exercises at home. The participants (45%) reported that they could have followed the booklet and the video for the entirety of their 30-minute Pilates practice. The participants (30%) also could fit the time to exercise in the same days during the six-week programme. The participants (10%) reported that they would prefer to practice Pilates at home rather than at a studio. Of the participants, 42.5% would prefer to have an instructor and attend the class at a studio to exercise Pilates rather than exercising at home without supervision.

However, 27.5% had no time to practice the exercises at home and they only practiced the supervised exercises, 55% of the participants took longer than 30 minutes to perform all the exercises and 70% could not fit the home-based exercises into their schedule. In addition, many of participants (57.5%) said that it was difficult to do the exercises at home due to motivation issues and because they could not remember how to perform some of the exercises. Most of the participants (90%) preferred having a place to go to do the exercises with an instructor, where there is more discipline and motivation.

5.8.4 Findings

GEE test was used to analyse the Times (pre-test and after 12 weeks) after washout the groups crossed over, the Time (after 12 weeks) in total 28 weeks programme (T3), between the groups and interaction (see Table 25 and table 26).

The TUG showed a decrease from the pre-test to post 12 weeks ($p = 0.003$) in all groups, with no difference between the group's effects (see fig. 26).

The FRT showed an increase from the pre-training to post 12 weeks of training ($p=0.030$) and a decrease from the 12 weeks of no exercise to post 28 weeks ($p < 0.001$) in group 2. There was no difference for time and between the group's effects (see fig. 26).

The FES-16 and IPAQ showed no difference between time, groups and interactions. The groups scores maintained in the three times (T1, T2 and T3) during the seven months programme.

The postural stability for the mediolateral directions under eyes opened conditions showed a decrease from the pre-test to post 12 weeks ($p = 0.035$) in all groups, with no difference between the group's effects (see fig. 26).

The spatiotemporal parameters of gait such as cadence showed an increase from the pre-test to post 12 weeks ($p = 0.027$) and from the pre-test to post 28 weeks ($p= 0031$) in all groups, with a significance difference between the group's effects ($p = 0.019$) (see fig. 27).

The step time showed a decrease from the pre-test to post 12 weeks ($p = 0.003$) a decrease from the 12 weeks to post 28 weeks ($p = 0.031$), in all groups, with a significance difference between the group's effects ($p = 0.028$) (see fig. 27).

The stance time showed a decrease from the pre-test to post 12 weeks ($p = 0.019$), a decrease from the 12 weeks to post 28 weeks ($p = 0.007$), in all groups, with a difference between the group's effects ($p = 0.012$) (see fig. 27).

The double support time showed a decrease from the pre-test to post 12 weeks ($p = 0.006$), in all groups, with a difference between the group's effects ($p = 0.031$) (see fig. 28).

The velocity, stride and step length and swing time were no significant difference for time, between groups and interaction effects.

Table 17 Mobility, functional mobility, fear of falling and physical activity gives T1, T2 and T3 between groups.

Variables	*Groups*	*Mean (95% CI)*					*p-values*		
		Pre-test	*Post-12 weeks*	*Post-28 weeks*	*(F)*	*Power*	*Groups effects*	*Time effects*	*Interaction Group × Time*
TUG (s)	1	7.65 (7.35 to 7.94)*	7.42 (7.06 to 7.77)	7.25 (6.93 to 7.57)	0.05	0.12	0.720	**0.002***	0.256
	2	7.79 (7.36 to 8.22)*	7.32 (6.96 to 7.68)	7.45 (7.01 to 7.90)					
FRT (cm)	1	27.38 (25.11 to 29.65)	27.26 (25.09 to 29.90)	27.61 (25.56 to 29.67)	0.22	0.91	0.841	0.006	**0.001***
	2	27.23 (24.88 to 29.58)*	29.72 (27.93 to 31.50)*	24.63 (23.68 to 25.58)*					
FES-16	1	21.64 (18.43 to 24.85)	21.64 (19.48 to 23.80)	23.47 (20.29 to 26.65)	0.02	0.06	0.234	0.419	0.091
	2	19.47 (18.00 to 0.93)	22.00 (17.37 to 26.62)	19.35 (17.70 to 20.99)					
IPAQ (MET)	1	2.948 (2.100 to 3.796)	2.280 (1.379 to 3.180)	3.027 (2.113 to 3.941)	0.005	0.05	0.053	0.607	0.273
	2	2.177 (1.461 to 2.892)	2.154 (1.460 to 2.848)	1.688 (1.078 to 2.297)					

Note: values are Mean and 95% Confidence Interval (CI) for the pre-test, post 12 weeks and post-28 weeks. group 1: C-P (control-Pilates), group 2: P-C (Pilates-control) and Interactions between (groups and time).
Abbreviation: Functional Reach test (FRT), Time Up and Go (TUG), Falls efficacy scale (FES-16), IPAQ: Short International Physical Activity Questionnaire; METs: Metabolic Equivalent of Task.
Effect size, family (F). Tests represent a significant difference between time (*).
*Values statistically significant ($p \leq 0.05$) for time, groups and interactions effects.

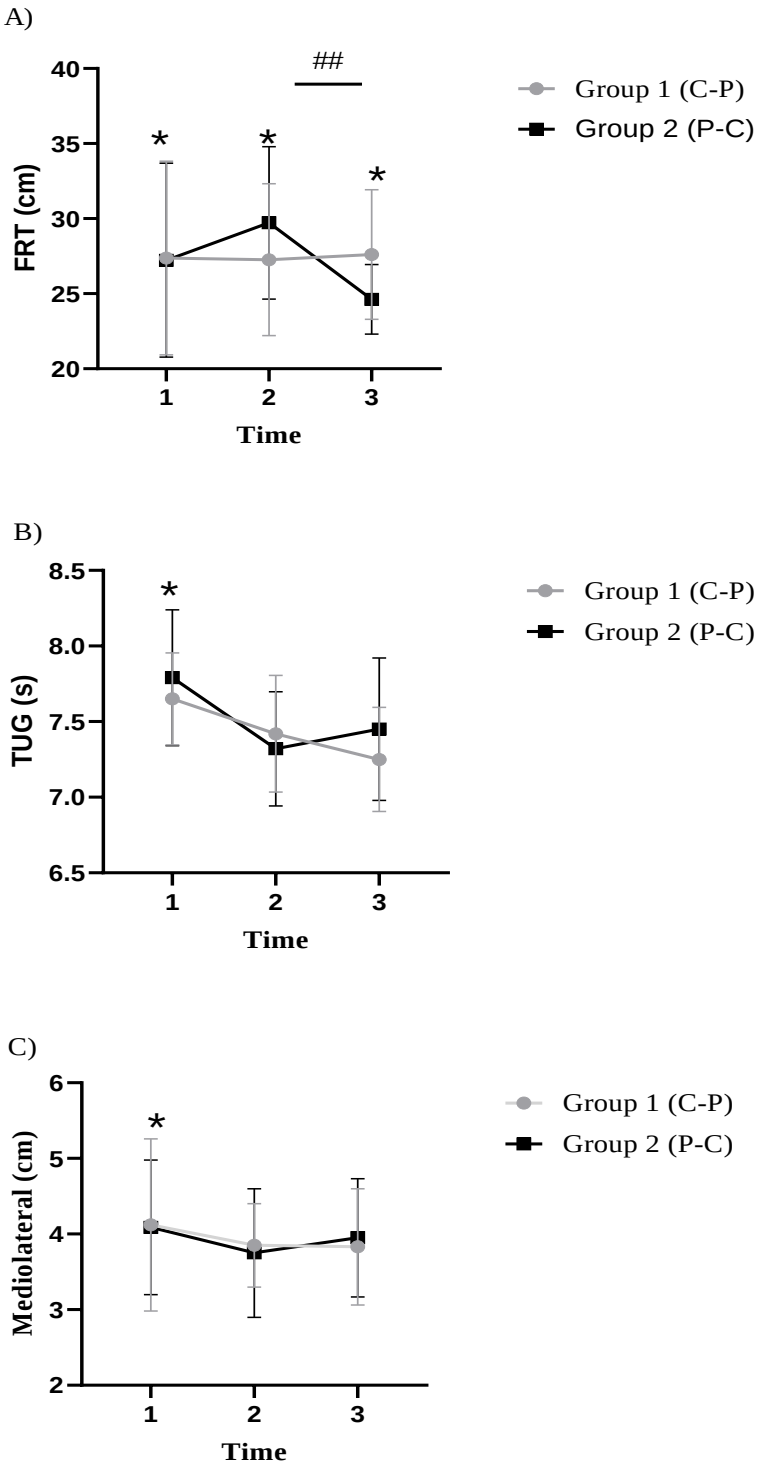

Figure 26 Mean and 95% confidence interval of Time Up and Go (TUG), Functional Reach Test (FRT), and mediolateral (ML) direction of postural stability for the pre-test (1), after 12 weeks of training (2), and after 28 weeks of training (3). Group 1 C-P (control-Pilates) and Group 2 P-C (Pilates-control). The symbol (*) indicates a significant difference in time effects, (#) indicates a significant difference between groups, and (##) indicates an interaction between (time and groups).

Table 18 Balance and Spatiotemporal parameters of gait gives T1, T2 and T3 between groups

Variables	*Groups*	*Mean (95% CI)*				*p-values*		
Platform/balance		*Pre-test*	*Post-12 weeks*	*Post-28 weeks*	*(F)*	*Power*	*Groups effects*	*Time effects*	*Group × Time*
AP (EO) cm	1	8.02 (6.66 to 9.38)	7.08 (6.07 to 8.09)	7.16 (6.08 to 8.24)	0.03	0.07	0.899	0.090	0.963
	2	8.09 (6.56 to 9.62)	6.90 (5.60 to 8.19)	6.96 (5.15 to 8.76)					
ML (EO) cm	1	4.12 (3.72 to 4.52)*	3.85 (3.59 to 4.11)	3.83 (3.47 to 4.20)	0.07	0.16	0.978	**0.040***	0.598
	2	4.09 (3.76 to 4.41)*	3.75 (3.45 to 4.05)	3.95 (3.63 to 4.27)					
AP (EC) cm	1	12.97 (10.20 to 15.74)	11.53 (10.56 to 12.51)	11.90 (10.13 to 13.68)	0.06	0.13	0.300	0.446	0.806
	2	11.57 (9.95 to 13.19)	11.17 (9.68 to 12.66)	10.81 (9.13 to 12.48)					
ML (EC) cm	1	7.13 (4.54 to 9.72)	5.21(4.26 to 6.16)	5.34 (4.40 to 6.28)	0.2	0.85	0.758	0.086	0.188
	2	6.02 (4.05 to 7.99)	6.35 (4.89 to 7.80)	4.66 (3.88 to 5.43)					
Spatiotemporal parameters of gait									
Cadence (Step/Min)	1	120.00 (119.12 to 124.87)*	124.27 (121.35 to 127.19)	124.60 (120.89 to 128.32)*	0.31	0.99	**0.019***	**0.014***	0.973
	2	117.50 (114.00 to 120.99)*	119.417 (116.46 to 122.74)	119.99 (117.52 to 122.46)*					
Velocity (cm/s)	1	145.54 (139.13 to 151.95)	148.78 (142.86 to 154.70)	149.10 (142.43 to 155.76)	0.21	0.94	0.081	0.229	0.969
	2	138.86 (131.46 to 146.26)	141.21 (134.55 to 147.88)	141.88 (136.04 to 147.72)					
Stride Length (cm)	1	143.50 (138.30 to 148.70)	144.39 (139.18 to 149.610)	143.85 (139.37 to 148.33)	0.08	0.20	0.554	0.770	0.980
	2	141.85 (137.20 to 146.49)	142.36 (137.96 to 146.77)	142.11 (137.80 to 146.41)					
Step Length (cm)	1	71.53 (69.04 to 74.01)	72.00 (69.51 to 74.49)	71.98 (69.73 to 74.22)	0.09	0.27	0.445	0.862	0.900
	2	70.63 (68.05 to 73.20)	70.72 (68.17 to 73.27)	70.46 (67.90 to 73.02)					
Step Time (s)	1	0.492 (0.480 to 0.505)*	0.484 (0.472 to 0.496)	0.484 (0.469 to 0.499)*	0.33	0.99	**0.028***	**0.003***	0.742
	2	0.515 (0.499 to 0.532)*	0.502 (0.488 to 0.516)	0.501 (0.490 to 0.513)*					
Swing Time (s)	1	0.372 (0.363 to 0.381)	0.369 (0.360 to 0.378)	0.368 (0.358 to 0.378)	0.34	0.99	0.285	0.156	0.845
	2	0.380 (0.369 to 0. 390)	0.374 (0.364 to 0.384)	0.375 (0.367 to o.383)					
Stance Time (s)	1	0.617 (0.599 to 0.635)*	0.602 (0.587 to 0.618)	0.597 (0.578 to 0.617)*	0.38	0.99	**0.012***	**0.005***	0.922
	2	0.644 (0.622 to 0.666)*	0.631 (0.615 to 0.647)	0.629 (0.612 to 0.645)*					
Double Sup Time (s)	1	0.250 (0.237 to 0.263)*	0.238 (0.227 to 0.249)	0.249 (0.219 to 0.279)	0.42	0.99	**0.031***	**0.005***	0.726
	2	0.278 (0.257 to 0.300)*	0.261 (0.249 to 0.272)	0.264 (0.250 to 0.277)					

Note: values are Mean and 95% Confidence Interval (CI) for the pre-test, post 12 weeks and post-28 weeks. group 1: C-P (control-Pilates), group 2: P-C (Pilates-control) and Interactions between (groups and time). Abbreviation: AP: anteroposterior; ML: mediolateral. Eyes open (EO), eyes closed (EC). Effect size family (F). Tests represent a significant difference between time (*). *Values statistically significant ($p \leq 0.05$) for time, groups, and interactions effects.

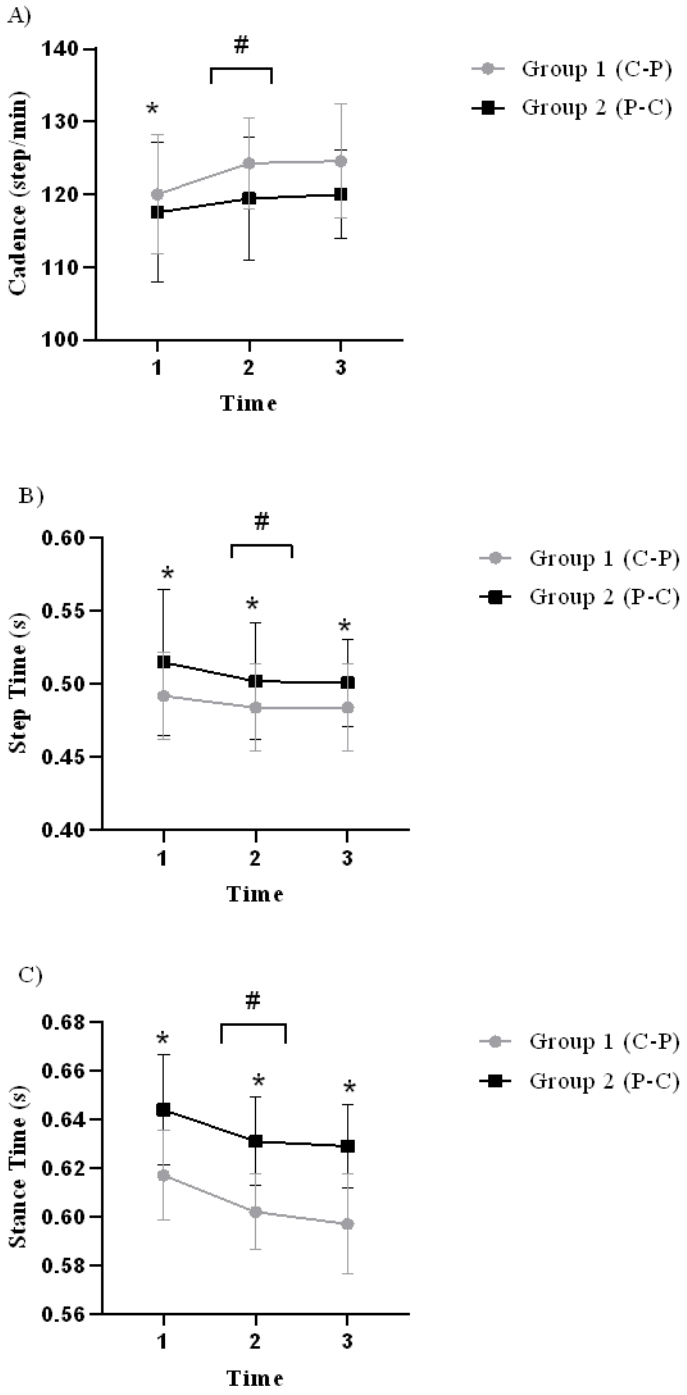

Figure 27 Mean and 95% confidence interval of gait: A) cadence, B) step time, and C) stance time for the pre-test (1), after 12 weeks of training (2), and after 28 weeks of training (3). Group 1 C-P (control-Pilates) and Group 2 P-C (Pilates-control). *The symbol* (*) indicates a significant difference in time effects, (#) indicates a significant difference between groups.

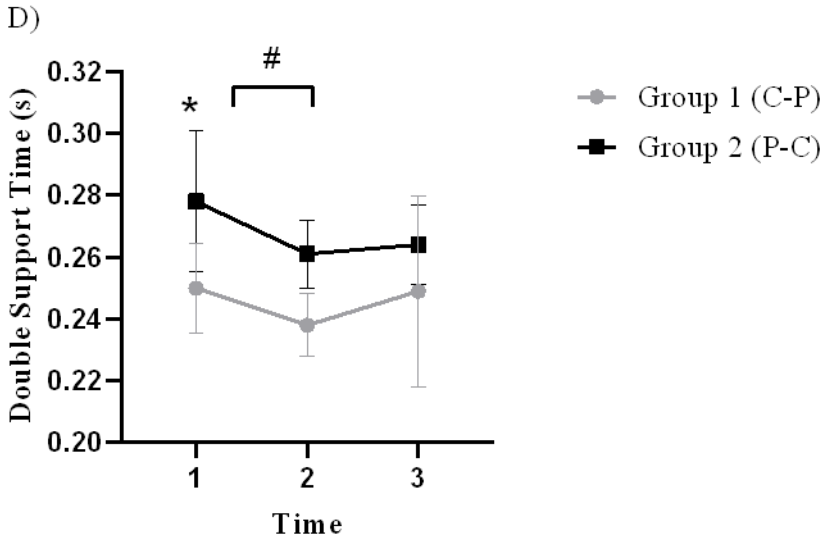

Figure 28 Mean and 95% confidence interval of gait: D) double support time for the pre-test (1), after 12 weeks of training (2), and after 28 weeks of training (3). Group 1 C-P (control-Pilates) and Group 2 P-C (Pilates-control). The symbol (*) indicates a significant difference in time effects, (#) indicates a significant difference between groups

5.9 Discussion

The 12-week Pilates program had positive in time effects for functional mobility ($p < 0.05$), postural stability ($p < 0.05$) and spatiotemporal parameters of gait ($p < 0.05$) in healthy people over 65 years of age. The findings also showed an effect between the groups for the spatiotemporal parameters of gait ($p < 0.05$) and interactions between the groups for the mobility test ($p < 0.001$). However, for the other variables the seven months programme with a period of 12 weeks of intervention, there was no significant difference between the groups ($p > 0.05$). The baseline assessment of the control group identified that they were older, had more health issues and there was a gender imbalance with more females than males. Despite these baseline variables there were no significant difference between the groups for the demographic details found. It is interesting to highlight that seven participants experienced falls in the control group during the study and no falls were reported by individuals in the Pilates group. Ultimately, it seems that this Pilates program may have been effective for the reducing falls risk factors.

5.9.1 Functional mobility and mobility

In general, an improvement in functional mobility was observed in healthy individuals during the 12-week period and the participants maintained their improvement until 28 weeks indifferently of the groups. In contrast, a study of a 12-week Pilates intervention with accessories (such as rubber bands and Swiss balls) showed no improvement in the TUG results for older women after training twice a week (Vieira et al., 2017). However, in another study in which a mat Pilates group focused on trunk core activation, improved TUG scores were observed in Asian participants after training for 12 weeks, three times per week (Hyun et al.,

2014). Moreover, mat Pilates without accessories may improve the range of movement in joints and mobility, resulting in better locomotion. TUG performance (the movements of sitting and standing) can be limited by the aging process, as older individuals may walk more slowly and decrease certain movements of the body, such as turning around. Johnson et al (2007) believed that after five weeks of Pilates, the subjects had great score in FRT due to improved motor control. Pata et al (2014) showed better improvement in TUG than the FRT after eight weeks of Pilates intervention including the chair and standing position exercises (Pata et al., 2014). In this study, the FRT showed positive results in relation to the interaction. The group of participants behaviours were different regarding the three tests' results. Even after the groups had crossed, there was an improvement over time in the two periods of 12 and 28 weeks after the intervention.

5.9.2 Fear of falling

There was no improvement in fear of falling for this population in relation to the FES-16 questionnaire, since the older adults included were physically active. A recent study found that decreased fear of falling and increased confidence in balance are related to increased physical activity and, consequently, decreased risk of falls and social problems in women over 60 after 12 weeks of Pilates (Aibar-Almazán et al., 2019). The questionnaire seems to be more effective for participants in this population who have limitations, such as health issues. This corroborates another study on Pilates that found an improvement in fear of falling in individuals with chronic lower back pain in the Pilates and physical therapy group and suggests that future studies should include a long-term intervention, a diary to record falls and a measure of balance to analyse participants (Cruz-Diaz et al., 2015).

5.9.3 Stabilometry

This study improved postural stability as a decrease in ML sway for single leg standing with eyes open, which turns less oscillations in the center of mass and improvement in the sensory motor function. The exercise protocol proposed in this study focused on performance in the standing position. The accessories included in the regimen, such as a spiky ball, a roller and the ring and bands, can be used to improve the sensorimotor system, control trunk and core stability and improve muscular strength, respectively. After comparing a Pilates group using a band with a Pilates group that did not use a band, Petrofsky et al. (2005) concluded that Pilates is more effective for balance when including accessories such as resistance bands to increase muscular strength. In contrast, Gabizon et al. (2016) found no improvement in balance control and health status after 12 weeks of mat Pilates with accessories such as a Thera band and a Swiss ball in comparison to a control group (Pilates exercises were performed in one-hour classes held three times a week). In another study, Donath et al. (2016) compared three groups: traditional balance exercises (n = 16), mat Pilates (n = 17) and a control group (n = 15). They found improvement in balance and trunk strength only in the balance group after eight weeks of training twice a week.

This study found no significant changes in the closed eyes condition, as without visual feedback, postural control changes to improve the somatosensory and vestibular inputs so that more oscillations occur in the center of mass with the result that higher values are observed due to efforts to maintain balance in the single leg test. The explanation for this is that open eyes are stimulated in the first instance in relation to the proprioceptive channel, whereas in the condition of closed eyes, stimulation involves the vestibular channel more compromising the vestibular

system (Franzoni et al., 2018). Higher values may show impairment of balance, indicating that individuals were more likely at risk of falling. In this study, the lower values showed improvement under the open eyes condition. There was no statistical significance in time and group effects under the closed eyes condition, although a decrease in all variables of balance was found.

5.9.4 Spatiotemporal parameters of gait

After twelve weeks of Pilates, little change in gait was observed, nevertheless there was an increase in cadence as well as a decrease in the following temporal parameters of gait: step, stance and double support time. The spatiotemporal parameters of gait were the only variables in which significant differences were found between the groups in this study. The three variables of gait (cadence, stance time, step time) were found to be significantly different between groups; there was an improvement over time after the 12-week and 28-week assessments. Only double support time showed no significant difference after the 28 weeks of the program. However, these four variables had a statistically significant difference between the groups. It is likely that the individuals in the control group experienced a ceiling effect. With regard to cadence the control group had higher values at baseline 122.0 step/min than in the Pilates group 117.50 step/min. In regards to velocity, participants who were allocated to the control group had higher baseline values; for example, a velocity of 145.54 cm/s compared to a velocity of 138.80 cm/s for the Pilates group. Similarity to this, a recent Pilates study suggesting ceiling effects by Choi et al. (2019) who found no improvement in temporal parameters and a higher score in cadence parameter, but there was no control group for comparison. In that study, 22 healthy older women improved step and stride length after ten weeks of training (thirty minutes, twice a week) (Choi et al., 2019).

Another study found that the spatiotemporal parameters of gait with higher cadence resulted in shorter periods of gait, as normal walking speed is equal to the product of step length and cadence. However, cadence increased with speed if older adults walk faster, the patterns of gait change and cadence increases as do step length and stride length (Fukuchi et al., 2019). The results showed an increased in velocity scores that meant to decrease the risk of falls. A literature review reported that self-selected walking speed decreased by 21% between the ages of 20 to 85 years (Grimmer et al, 2019).

The decrease in double support time corroborates the findings of the study by Scott et al. (2015), whereby non-recurrent fallers improve in the double support phase and that recurrent fallers showed no association in gait parameters over one year and two months. After two years and eight months, the double support time increased and step length and swing time decreased (Scott et al., 2015).

5.10 Limitations

There are several limitations to this study, which included an intervention programme (Pilates-12 week and control-12week) and four weeks of washout period. Participant dropout was high (n = 20). Most of these dropouts occurred when the participants were allocated (n = 12) before the crossover; the remaining dropouts occurred after the crossover (n = 8). One participant was not included in the physical testing. Within this study the risk of bias is high and this should be noted; this was an unblinded study; there was a significant loss to follow-up and differential drop-outs between the study groups which could have affected the results. In addition, the spatiotemporal parameters of gait were different between the groups at the beginning for the four variables; this shows differences in time and group effects for both groups (C-P and P-C) all over the time.

Other limitations are that the groups were of different sizes at the beginning. The intention-to-treat analysis was not carried out between baseline and T1. However, this study included the GEE analysis which allowed the performance of the intention-to-treat analysed between T2 and T3. The missing data for these two tests were clustered. The generalised estimating equation (GEE) was used to perform a robust analysis. This method permitted a longitudinal analysis of cluster data, as GEE fits a marginal model (Wang, 2014).

The models permit correlations in the data by repeated measures on the same subjects all the time (Crouchley & Davies., 1999).

This study had a four-week washout period and there was insufficient time to remove the residual effects of the Pilates programme. However, this is not precise because this study did not evaluate the participants after the washout period.

The participants in the control group could have engaged in exercise routines, which may have affected the outcome measures in those participants. In addition, learning effects for the clinical assessment and the Hawthorne effect may have affected the outcome measures (McCarney et al., 2007).

5.11 Recommendations for Future Research

Future research should include a longer period of washout to verify the duration of the residual effects. The crossover study follows a sequence and may have order effects that depend on which type of treatment the participant was allocated, thus affecting the results. The results of this study confirmed that there is a need for a large, prospective double blind RCT (no crossover). Pilates exercises with a long intervention period can be compared to a group of exercises at home and or a supervised group to be included in a follow-up fall prevention study.

Researchers should include specific groups for a specific population, limit the criteria for inclusion of participants and focus on balance and gait training. In addition, future studies should prepare and plan each class in terms of the intensity level of the exercises as this is lacking in the Pilates literature. The instructions should be split to provide a few exercises each week to the participants to avoid them looking ahead and practicing at home. The results suggests that exercising Pilates at home is cost-effective, avoids difficulties with transportation e.g. for participants who do not have the support of family members or other people. The cost of professional became lower than in the presential class.

Pilates is easy to practice at home and the individual may fit it into their daily time schedule, following the instructions given by a video and booklet. However, exercises at home have to be checked by a professional frequently, to improve the individual's performance, clarify doubts about exercises and encourage the individual to exercise regularly.

5.12 Conclusion

The crossover study had positive effects that participants did not have falls when they were allocated to the Pilates intervention although further research is needed to verify these findings. A twelve-week Pilates intervention improved functional mobility, mobility, balance, however there were no differences between groups in these healthy older adults. The findings demonstrated an increase in cadence and a decrease in the temporal parameters of gait. The changes in spatiotemporal parameters of gait were different all over time period for all groups. The effect of the Pilates intervention suggests that long-term intervention in healthy older people after 12 weeks of Pilates with a supplementary home programme still needs further investigation. Further study in this area is warranted.

5.13 Clinical Relevance

- Falls are a leading cause of morbidity and mortality in older adults
- A 12-week Pilates program, with supplementary home-based exercises, had positive effects on functional mobility, postural balance which, may reduce the risk of falls.
- Advancing age is associated with decreased balance control and deterioration of motor skills, which affects walking ability. The spatiotemporal gait parameters changed over time during seven months programme.

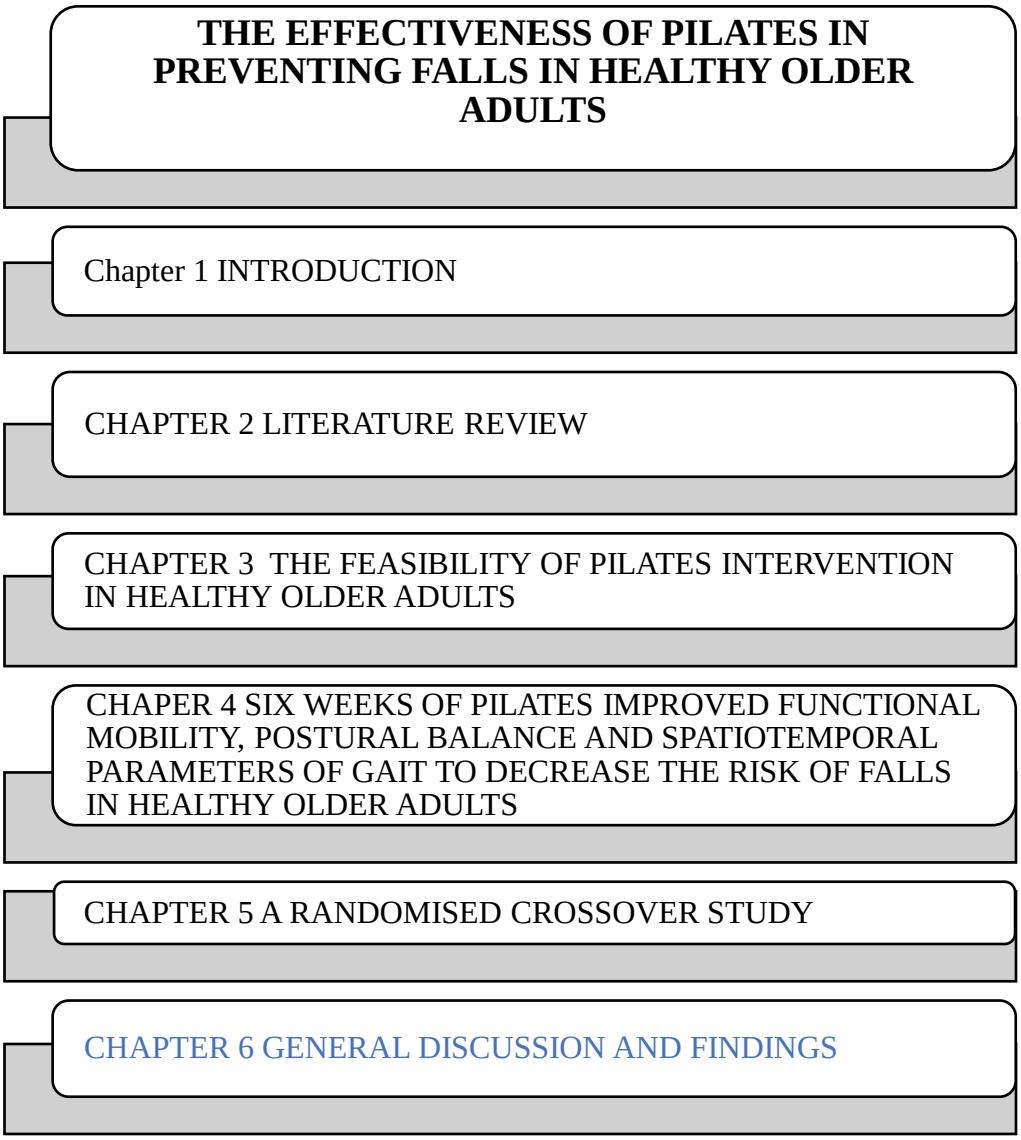

Figure 29 Layout of the thesis

CHAPTER 6 GENERAL DISCUSSION AND FINDINGS

The researcher conducted three studies to investigate the effectiveness of the Pilates exercises intervention in decreasing the risk of falls in older adults, examining the following outcomes: mobility, functional mobility, fear of falling, physical activity, postural balance and the spatiotemporal parameters of gait. A systematic review and meta-analysis were undertaken to synthesise the research literature and provide an evidence base for a Pilates intervention to decrease the risk of falls.

The systematic review and meta-analyses included 12 RCT studies. Most of the Pilates interventions described in the studies were carried out twice weekly for one hour over 12 weeks, howevert only eight studies were considered to be of moderate to high quality according to the PEDro scale (https://pedro.org.au/english/resources/pedro-scale/).

Most of the studies used mixed, home-based interventions with a mat, equipment and accessories. The meta-analysis found that Pilates interventions better improved functional mobility than other forms of exercise; mobility was improved compared to both no-exercise groups and other-exercise groups. Furthermore, gait, fear of falling and postural stability were improved compared to control groups (i.e. no exercise).

Generally, the Pilates method intervention studies reported a similar number of sessions per week (8–12), and most of the studies found improvement in healthy older adults. Postural balance, mobility and general functional mobility were the main reported outcomes and the most common outcomes among the studies.

The results suggest that older adults experience positive effects, but these results should be interpreted with caution due to the statistical heterogeneity of the meta-analysis. In terms of outcomes, there was a lack of studies that analysed the

parameters of gait in healthy subjects using RCTs, so long-term RCT follow-ups are required.

This research aimed to investigate the effectiveness of Pilates interventions in decreasing the risk of falls in older adults; it included a supplementary home-based, six-week programme, pre- and post-intervention testing and an RCT study of a 12-week intervention within a seven-month programme.

Exercises targeting balance, functionality, mobility, gait and strength are suitable for improving the independence of the older population and preventing falls, however the success of Pilates intervention programmes depends on the exercise dosage with regard to intensity, length and frequency. The type of intervention also affects success, including the use of equipment, Pilates mats and accessories as well as whether the intervention is home-based or combined. Success also depends on whether the participant groups are more or less active, fallers or non-fallers or comprising sedentary participants. It is also important to establish a training protocol programme for short- and longer-term interventions to ensure a positive effect on the older population. This research established the feasibility of a six-week training protocol for selected measures and variables.

The cohort study confirmed the results of the six-week mat Pilates intervention with supplementary home-based exercises, showing that a short-term Pilates intervention positively affected the outcomes of mobility, functional mobility, the spatiotemporal parameters of gait and postural balance in the mediolateral direction in active, healthy older adults who practiced traditional Pilates.

No participants fell during the study. However, it is important to note that the factor of whether the participants had practiced Pilates before the study was implemented had important effects on the outcomes. It should also be noted that the analysis was

an extension of the paired-samples t-test (to allow for the between-participants factor of Pilates) and an interaction term (between the time and Pilates factors). The cohort study sought to greatly reduce error variance by using subjects who served as their own controls. The repeated-measures design is broadly recognised to require vastly fewer data points than one in which blocking by participants is not or cannot be done (e.g. in-life testing). Furthermore, doubly multivariate analyses were conducted when possible (not only to capitalise on the correlation within subjects across the two time points but also to take advantage of the correlation between left and right measurements of the same individual).

The randomised crossover study using a 12-week Pilates programme with supplementary home-based exercises had positive effects and changed the scores in time effects (pre- and post-test) on mobility, functional mobility and postural balance in the mediolateral direction. There was no difference between the groups for these variables, however the scores for spatiotemporal parameters of gait changed over the three times points of the programme, indicating that the groups were initially different. The Pilates intervention yielded a positive effect compared to the control group with regards to the number of falls occurring in the control group, even though the crossover study found a decrease in the risk of falls in the older adult population.

The participants in this study had lower levels of physical activity, and they were older on average than the previous group (the cohort study). Nevertheless, their general mobility showed greater improvement than was found without accessories and with a short intervention period. The participants exhibited less improvement at 12 weeks than at six, but this result cannot account for many other potentially causal factors, such as the intervention (number of weeks, period of intervention,

washout period, whether accessories were used) and participant criteria (fallers vs non-fallers, active vs less active, experience with Pilates before the study vs no prior Pilates experience, health status). The chosen intervention methods are described on page 64 (chapter 3) and page 114 (chapter 5). Finally, exercises that included balance and functional training decreased falls compared with the non-active participants in the control group (Sherrington and Fairhall, 2020).

6.1 Limitations

Only 12 articles were included in the literature review, as there have been few randomised controlled trials in this area. Little evidence exists on the positive effects of Pilates on the variables of gait and fear of falling, suggesting that further studies in this area are warranted.

After six weeks of Pilates training, no significant changes were observed for balance performance in single-leg standing or in responses to the Fall Efficacy Scale questionnaire, but the population was physically active, and a longer intervention period may be needed. Nevertheless, the study did not compare the Pilates intervention with the control group and lacked a blind assessor.

After 12 weeks of Pilates training, regardless of the control group, no differences were observed between the groups in functional mobility or postural balance. The spatiotemporal parameters were significantly different in the time and groups effects in the following variables: cadence, step time, stance time and double support time. However, the groups baseline had been different since the beginning of the intervention.

In addition, a washout period of four weeks revealed no effects. In the crossover study, the analyses did not include any factors or covariates to avoid error type;

however, this study was unlikely to include covariates and a factor (Pilates) because of the inclusion of three tests, the group comparison and the number of variables included for the sample size. For the first part of this study, before the groups crossed over, it was possible to conduct the analyses between the two tests, and the intention was to adjust the covariates in the analyses to determine the possible effects. Kahan and Morris (2012) note that adjusted analyses increase the power and probability of correcting error rates.

Furthermore, the RCT had high dropout rates and a lack of intention to treat, and it was an unblinded study. Most of participants in both studies (cohort and RCT) were women. In addition, the participants probably had a learning effect that should be accounted for with regard to the clinical tests (TUG and FRT). The different lengths of time and different number of weeks of the interventions also produced different effects among the trial participants, which can lead to measurement bias. This can impact the validity of such findings as those of FRT, TUG, balance and gait. Other potential sources of bias, particularly in the RCT, include the differing number of participants between the groups, the random allocation sequence, the method design, the exclusion criteria, the incomplete baseline data limitation and treatment effects.

6.2 Contribution to Knowledge

This Pilates intervention research was the first to be implemented in Ireland and is of value to Pilates instructors, health care professionals, researchers and the older population. This thesis contributes to research on falls through the use of six- and 12-week novel Pilates protocol programmes with supplementary at-home exercises and measurable outcomes, such as the spatiotemporal parameters of gait. The

analyses represent original work, and no research of this type had previously been undertaken in Ireland.

The programme was based on six- and 12-week interventions with twice-weekly supervised classes supplemented by home activities three times per week. The results show that the participants did not experience falls during the period of practicing Pilates. This thesis can benefit Pilates instructors and health care professionals planning to implement the Pilates method in multidisciplinary teams in the public health system. This Pilates programme can guide clinical Pilates practice and provide information to improve fall prevention programmes.

What was already known?

i) Pilates has become a popular form of exercise worldwide.
ii) Pilates improves balance, postural stability, mobility, functional mobility, quality of life and functional capacity and lessens the fear of falling, which may decrease the risk of falls.
iii) Pilates is known to enhance health status, muscle strength, flexibility, functional autonomy, muscle endurance, body composition and aerobic endurance.
iv) The World Health Organisation (WHO) recommends tai chi, (holistic) yoga and balance exercises to prevent falls.
v) Pilates studies need to improve in quality and rigor, as more definitive evidence is needed through high quality RCTs.

What are the new findings?

i) This systematic literature review found that, compared to control groups, a Pilates intervention yielded no better improvement in functional mobility

than other exercises. However, a Pilates intervention yielded greater improvement in mobility than other exercises when compared to control groups.

ii) A Pilates intervention improved mobility, functional mobility, mediolateral directions and spatiotemporal parameters of gait.

iii) Pilates had no improvement in fear of falling and postural stability with eyes closed after six or 12 weeks of a mat Pilates intervention.

The RCT studies included in the meta-analyses provide the highest level of evidence of the impact of interventions on preventing falls in older adults. The novelty of this research is that all the measures were validated and were of high quality in implementing a short and longer period of intervention to minimise the risk of falls in older adults. There was previously little research in this area. The RCT, which developed a protocol for falls prevention, has important implications for developing evidence-based practice guidelines and clinical recommendations.

The RCT provides the most reliable type of evidence, as it minimises confounding factors that may influence the results. The crossover design is high quality methodological approach to employ, nevertheless in physical activity intervention the washout phase must be long enough to rule out any residual effects. It is difficult to implement a longer period of follow-up with a large sample of older adults and drop-outs occurred in relation to various difficulties, such as transportation, weather, holidays and sickness.

6.3 Recommendations for future researchers

It is recommended that future researchers follow the gold standard approach in conducting systematic reviews, which includes published RCTs and a greater number of RCTs with methodological rigour, to improve the quality of evidence.

Additional high-quality studies, different measurements and detailed descriptions of the proposed exercises are needed to clarify the effects of Pilates on other variables, such as number of falls during the intervention programme and the spatiotemporal parameters of gait related to reducing the risk of falls in older adults.

Future researchers can adapt the protocols used in this six- and 12-week training research to inform the participant criteria in their studies. They can also use this research to bridge the gaps in evidence-based Pilates studies. Further RCTs of Pilates interventions are required with longer follow-ups, with reporting of falls incidence and with other exercise groups as comparators to better determine the effectiveness of Pilates in preventing falls.

Future researchers should expand the inclusion criteria to include older adults in terms of measuring functional mobility, activity level, experience with Pilates and faller or non-faller condition. More rigorous methods should be applied, such as larger sample sizes, double-blind trials, random allocation, concealed assignment and intention-to-treat analysis. A longitudinal study design can be used to measure gait, functional mobility and postural stability. The designed study could also be conducted in place to prevent participants from dropping out. The power and sample size depend on the employed methods design, the number of tests and the types of analysis

The sample size for future researchers that wish to employ a RCT study can be determined using G*Power software version 3.1 (Universität Düsseldorf, Germany) for a power of about 0.90. For a pre- and post-intervention test in RCT studies, a sample of n=36 will be needed (significance level = .05; correlation coefficient = 0.5) based on the research data of Mesquita et al. (2015), Aibar-Almazán et al. (2019) and Newell et al. (2012).

Future researchers could conduct trials with participants who have a specific disease that impacts gait and balance, e.g. multiple sclerosis, Parkinson's, stroke or cognitive impairment. The methods could include three arms and compare the effectiveness of the mat vs mat with accessories and control group or home-based exercise; alternatively, researchers could include a different exercise, such as yoga or tai chi, and different intervention lengths, such as 6, 12 or 20 weeks. A falls diary should be recorded, for which the participants could use an electronic system or app system (mobile phone).

To improve Pilates exercises, data collection could be done with different instruments, such as measuring gait using 3D equipment to observe whole movement and inertial unit movement (IMU) of various planes as well as recording electromyographic (EMG) changes (contraction of the muscles for a specific movement during exercise).

6.4 Conclusion

Falls in older adults are a serious problem for health services worldwide. This research includes interventions and assessments to decrease the risk of falls and can reduce the health service burden and improve physical activity in older adults. This thesis offered a literature review that synthesised evidence from the past 10 years to provide a clear rationale for the contribution of Pilates to fall prevention protocols.

This study has highlighted the use of six- and 12-week Pilates interventions for fall prevention in an older population to improve general functionality, mobility, gait and balance. The two most important elements for detecting the risk of falls in older adults are functional mobility and postural balance. Pilates may positively influence

falls risk factors, which may decrease the risk of falls. Further high-quality studies with methodological rigour are required to provide definitive evidence for the health system.

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APPENDIX

1 Consent Form

1. I confirm that I have read the participant information sheet dated __/__/__ for the above study and I have had the opportunity to ask questions. ☐

2. I am satisfied that I understand the information provided and have had enough time to consider the information. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected in any way, and without my medical care being impacted in any way. ☐

4. I agree to take part in the above study. ☐

_____	_____	_____
Participant Name	Date	Participant Signature
_____	_____	_____
Researcher Name	Date	Researcher Signature

College of Medicine, Nursing& Health Sciences NUI Galway.

2 Research Ethical Approval

NUI Galway
OÉ Gaillimh

RESEARCH SUPPORT SERVICES
ENABLE | DEVELOP | PROMOTE

4th June 2015

Dear Ms Donatoni Da Silva

Re **Ethics Ref 15/May/02 - The Efficacy of Pilates in Falls Prevention in Healthy Older Adults**

I write to you regarding the above proposal which was submitted for Ethical review. Having reviewed your response to my letter, I am pleased to inform you that your proposal has been granted **APPROVAL.**

All NUI Galway Research Ethic Committee approval is given subject to the Principal Investigator submitting annual and final statements of compliance. The first statement is due on or before 30th January 2016. Please see section 7 of the REC's Standard Operating Procedures for further details which also includes other instances where you are required to report to the REC.

Yours Sincerely

Allyn Fives

Chair, Research Ethics Committee

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3 Written Participant information sheet

1.1-Title:

The effectiveness of Pilates to prevent falls in healthy older adults.

3 Information sheet

2- Invitation to take part in the study

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. This Participant Information Sheet will tell you about the purpose, risks and benefits of this research study. If you agree to take part, we will ask to ask you to sign a Consent Form. If there is anything that you are not clear about, we will be happy to explain it to you. Please take as much time as you need to read it. You should only consent to participate in this research study when you feel that you understand what is being asked of you, and you have had enough time to think about your decision.

Thank you for reading this.

3- Purpose of the Study

This is a study of the effect of Pilates in the prevention of falls in older people in Ireland. The outcomes assessed will include questionnaires and tests of physical activity, balance, foot pressure, mobility, gait, cognition and falls.

Our study is looking at the effect that participating in Pilates has on balance, breathing, stretching, and coordination. In particular, we are interested in people over 65 years old, who enjoy doing exercises. We wish to measure your level of function with questionnaires and tests so that we can compare it with people who not practising Pilates.

3.1- Participants

Participants will be healthy adults over the age of 65 years old.

3.2- Study Design

This study will have two groups. The Pilates Group 1 (GP) practice Pilates and control group 2 (CG) do not practice Pilates. After three months the groups will be crossed over (i.e. the groups will swap over) after a break of one month.

- GROUP INTERVENTION – practice Pilates
- Washout period (Break) of one month – no practice
- CONTROL GROUP - do not practice Pilates.

4- Taking Part

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect your rights in any way.

What will happen to me if I take part?

You will be a part of a research group for a period of time and you will practice Pilates exercises, and answer questionnaires and tests.

What will happen at each visit (if appropriate)?

The Classes will take a place at NUI Galway.

1-The Researcher will give you the information, and explain the theory about Pilates and how it works.

2-Assessments will be carried out. This will include questionnaires and simple tests.

Participants will be allocated to mixed female and male groups. The exercises classes will be twice weekly for three months a total 24 sessions with older adults with both groups;

Participants should wear comfortable clothes for exercises

Participants will get a home Pilates exercise programme and a video will be share with exercises demonstrated by the instructor.

What are the possible benefits?

There are no benefits other than the benefit of regular exercise.

The study includes a questionnaire that measures your well-being in the recent past. You might find, while you are answering it, that you would like to talk to someone about some of the issues it raises. We will be happy to recommend someone to you.

5- Confidentiality

All information that is collected about you during the course of the research will be kept strictly confidential and will not be shared with anyone else. The information collected in this research study will be stored in a way that protects your identity. The recordings will be transcribed for analysis. We will store the original recordings securely for five years after which they will be destroyed. Results from the study will be reported as group data and will not identify you in any way.

All information that is collected about you during the course of the research will be kept strictly confidential and will not be shared with anyone else. The information collected in this research study will be stored in a way that protects your identity. We will store the original data securely for five years after which they will be destroyed. Results from the study will be reported as group data and will not identify you in any way.

Whom do I contact for more information or if I have further concerns?

You should contact Professor Agnes Shiel

If you have any concerns about this study and wish to contact someone independent and in confidence, you may contact the Chairperson of the NUI Galway Research Ethics Committee, c/o Office of the Vice President for Research, NUI Galway, ethics@nuigalway.ie

4 Short FES-I questionnaire

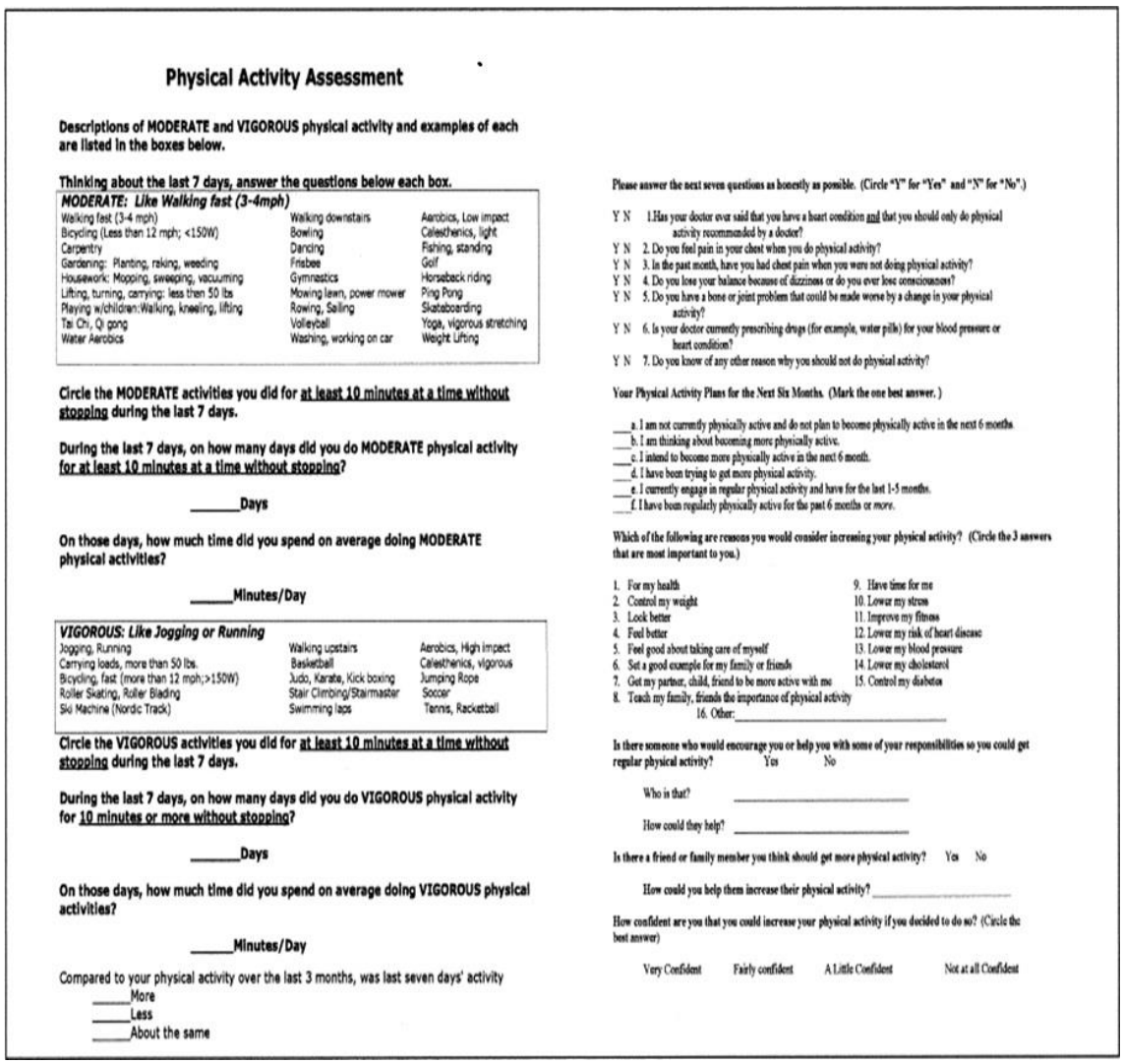
Short FES-I

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity, please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned *1*	*Somewhat concerned* *2*	*Fairly concerned* *3*	*Very concerned* *4*
1	Getting dressed or undressed	*1* †	*2* †	*3* †	*4* †
2	Taking a bath or shower	*1* †	*2* †	*3* †	*4* †
3	Getting in or out of a chair	*1* †	*2* †	*3* †	*4* †
4	Going up or down stairs	*1* †	*2* †	*3* †	*4* †
5	Reaching for something above your head or on the ground	*1* †	*2* †	*3* †	*4* †
6	Walking up or down a slope	*1* †	*2* †	*3* †	*4* †
7	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* †	*2* †	*3* †	*4* †

Kempen GIJM, Yardley L., Haastregt JCM van, Zijlstra GAR, Beyer N, Hauer K, Todd C.

5 Physical Activity Assessment (PAAT) questionnaire



Physical Activity Assessment

Descriptions of MODERATE and VIGOROUS physical activity and examples of each are listed in the boxes below.

Thinking about the last 7 days, answer the questions below each box.

MODERATE: Like Walking fast (3-4mph)

Walking fast (3-4 mph)	Walking downstairs	Aerobics, Low impact
Bicycling (Less than 12 mph; <150W)	Bowling	Calesthenics, light
Carpentry	Dancing	Fishing, standing
Gardening: Planting, raking, weeding	Frisbee	Golf
Housework: Mopping, sweeping, vacuuming	Gymnastics	Horseback riding
Lifting, turning, carrying: less then 50 lbs	Mowing lawn, power mower	Ping Pong
Playing w/children:Walking, kneeling, lifting	Rowing, Sailing	Skateboarding
Tai Chi, Qi gong	Volleyball	Yoga, vigorous stretching
Water Aerobics	Washing, working on car	Weight Lifting

Circle the MODERATE activities you did for at least 10 minutes at a time without stopping during the last 7 days.

During the last 7 days, on how many days did you do MODERATE physical activity for at least 10 minutes at a time without stopping?

_____Days

On those days, how much time did you spend on average doing MODERATE physical activities?

_____Minutes/Day

VIGOROUS: Like Jogging or Running

Jogging, Running	Walking upstairs	Aerobics, High impact
Carrying loads, more than 50 lbs.	Basketball	Calesthenics, vigorous
Bicycling, fast (more than 12 mph;>150W)	Judo, Karate, Kick boxing	Jumping Rope
Roller Skating, Roller Blading	Stair Climbing/Stairmaster	Soccer
Ski Machine (Nordic Track)	Swimming laps	Tennis, Racketball

Circle the VIGOROUS activities you did for at least 10 minutes at a time without stopping during the last 7 days.

During the last 7 days, on how many days did you do VIGOROUS physical activity for 10 minutes or more without stopping?

_____Days

On those days, how much time did you spend on average doing VIGOROUS physical activities?

_____Minutes/Day

Compared to your physical activity over the last 3 months, was last seven days' activity

_____More
_____Less
_____About the same

Please answer the next seven questions as honestly as possible. (Circle "Y" for "Yes" and "N" for "No".)

Y N 1.Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
Y N 2. Do you feel pain in your chest when you do physical activity?
Y N 3. In the past month, have you had chest pain when you were not doing physical activity?
Y N 4. Do you lose your balance because of dizziness or do you ever lose consciousness?
Y N 5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
Y N 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
Y N 7. Do you know of any other reason why you should not do physical activity?

Your Physical Activity Plans for the Next Six Months. (Mark the one best answer.)

___a. I am not currently physically active and do not plan to become physically active in the next 6 months.
___b. I am thinking about becoming more physically active.
___c. I intend to become more physically active in the next 6 month.
___d. I have been trying to get more physical activity.
___e. I currently engage in regular physical activity and have for the last 1-5 months.
___f. I have been regularly physically active for the past 6 months or *more*.

Which of the following are reasons you would consider increasing your physical activity? (Circle the 3 answers that are most important to you.)

1. For my health
2. Control my weight
3. Look better
4. Feel better
5. Feel good about taking care of myself
6. Set a good example for my family or friends
7. Get my partner, child, friend to be more active with me
8. Teach my family, friends the importance of physical activity
9. Have time for me
10. Lower my stress
11. Improve my fitness
12. Lower my risk of heart disease
13. Lower my blood pressure
14. Lower my cholesterol
15. Control my diabetes
16. Other:_____

Is there someone who would encourage you or help you with some of your responsibilities so you could get regular physical activity? Yes No

Who is that? _____

How could they help? _____

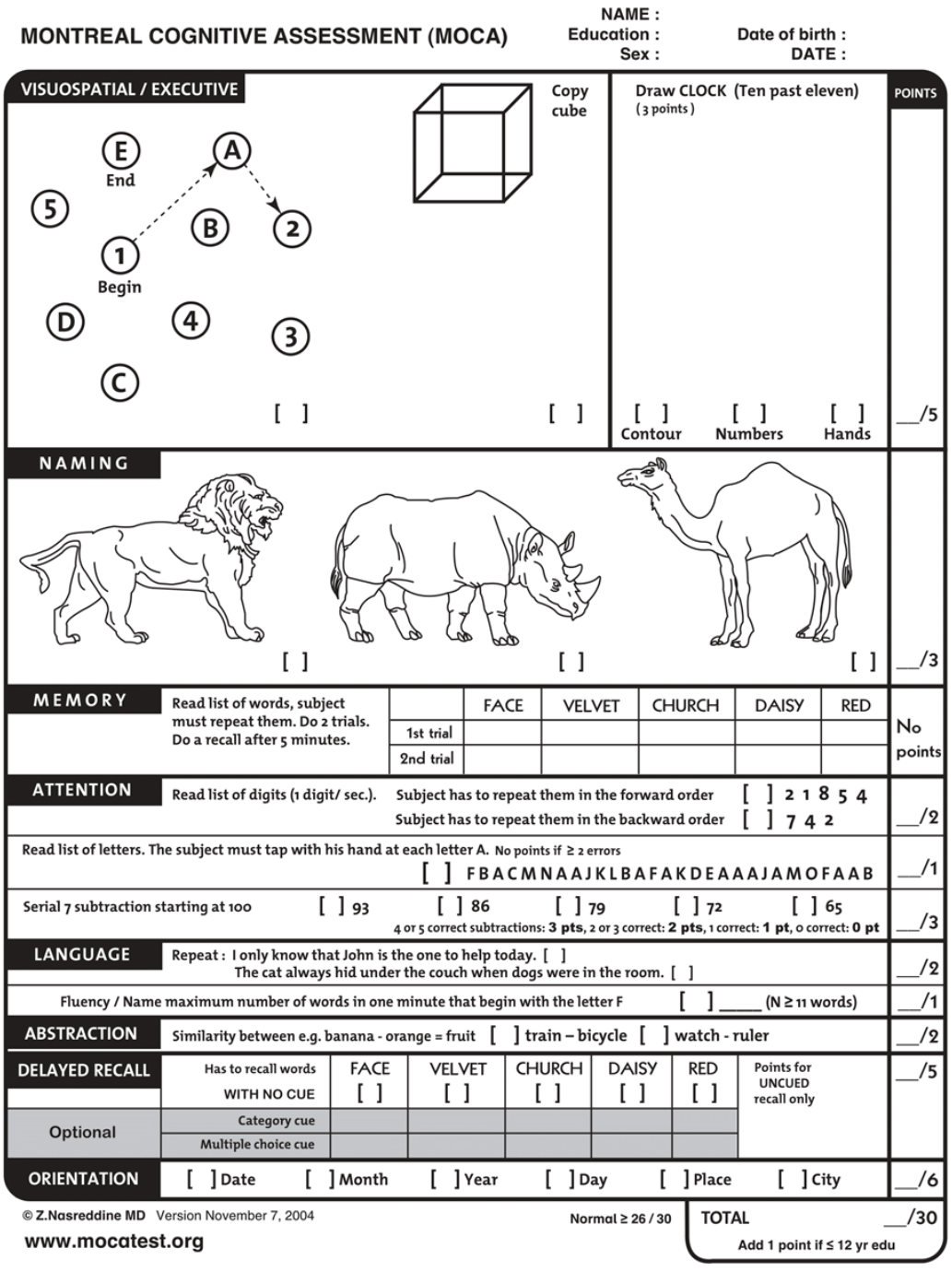
Is there a friend or family member you think should get more physical activity? Yes No

How could you help them increase their physical activity? _____

How confident are you that you could increase your physical activity if you decided to do so? (Circle the best answer)

Very Confident Fairly confident A Little Confident Not at all Confident

6 Montreal cognitive assessment



MONTREAL COGNITIVE ASSESSMENT (MOCA)

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS

Copy cube [ ]

Draw CLOCK (Ten past eleven) (3 points)
[ ] Contour [ ] Numbers [ ] Hands

__/5

NAMING

[ ] [ ] [ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]

__/2

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

__/1

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

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	FACE	VELVET	CHURCH	DAISY	RED	Points for UNCUED recall only
		[ ]	[ ]	[ ]	[ ]	[ ]	
Optional	Category cue						
	Multiple choice cue						

__/5

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

__/6

© Z.Nasreddine MD Version November 7, 2004
www.mocatest.org

Normal ≥ 26 / 30

TOTAL __/30
Add 1 point if ≤ 12 yr edu

7 FES-I

FES-I

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	*Somewhat concerned 2*	*Fairly concerned 3*	*Very concerned 4*
1	Cleaning the house (e.g. sweep, vacuum or dust)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
2	Getting dressed or undressed	*1* ☐	*2* ☐	*3* ☐	*4* ☐
3	Preparing simple meals	*1* ☐	*2* ☐	*3* ☐	*4* ☐
4	Taking a bath or shower	*1* ☐	*2* ☐	*3* ☐	*4* ☐
5	Going to the shop	*1* ☐	*2* ☐	*3* ☐	*4* ☐
6	Getting in or out of a chair	*1* ☐	*2* ☐	*3* ☐	*4* ☐
7	Going up or down stairs	*1* ☐	*2* ☐	*3* ☐	*4* ☐
8	Walking around in the neighbourhood	*1* ☐	*2* ☐	*3* ☐	*4* ☐
9	Reaching for something above your head or on the ground	*1* ☐	*2* ☐	*3* ☐	*4* ☐
10	Going to answer the telephone before it stops ringing	*1* ☐	*2* ☐	*3* ☐	*4* ☐
11	Walking on a slippery surface (e.g. wet or icy)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
12	Visiting a friend or relative	*1* ☐	*2* ☐	*3* ☐	*4* ☐
13	Walking in a place with crowds	*1* ☐	*2* ☐	*3* ☐	*4* ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
15	Walking up or down a slope	*1* ☐	*2* ☐	*3* ☐	*4* ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* ☐	*2* ☐	*3* ☐	*4* ☐

FES-I: Prof Lucy Yardley and Prof Chris Todd

8 Questions

DURING THE PAST YEAR HOW OFTEN HAVE YOU FALLEN OVER?

1 NEVER

2 ONCE

3 TWICE

4 MORE

IN GENEERAL ARE YOU AFRAID OF FALLING OVER? (FEAR OF FALLING)

1 NOT AT ALL

2 A LITTLE

3 QUITE A BIT

4 VERY MUCH

9 International Physical Activity Questionnaire

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

10 Congress and conferences attended

24th Annual Congress of the European College of Sport and Science. ECSS. Prague, Czech Republic 2019.

25th Congress of the European Society of Biomechanics. ESB. Vienna, Austria 2019 (Congress).

Introduction to Public and Patient Involvement (PPI). NUI Galway, Ireland. 2018

8th World Congress of Biomechanics. Dublin, Ireland 2018 (Congress).

3rd Transatlantic Wound Science and Podiatrist Medicine. Conference. Galway, Ireland 2017.

College of Medicine, Nursing & Health Sciences (CMNHS). Research day. NUI Galway 2017(Congress).

Podiatric Medicine - A journey of human movement Conference. Glasgow, UK 2017.

XVIII Congress of the Italian Society for movement of the analysis in Clinic. SIAMOC. Torino, Italy 2017.

Biomechanics Workshop for SMEs. 2016.

Postgraduate Study Day in Ageing Research. Irish Gerontological Society (IGS). Looking to the future of older Persons care services. Dublin Ireland, 2016.

A Masterclass in Physical Activity Programming. National Institute for Preventive Cardiology, NIPC, Galway Ireland 2015.

Pilates for the Older Person. Body Control Pilates, BCP, London.UK 2014.

11 Advertisement of the research

DonatonidaSilva.L, McNamara, Denise. Pilates is good for the young and old. Connacht tribune, Galway, p. 12, 05 Jan. 2018. (Invited)

FASHION & BEAUTY
DENISE McNAMARA

denise.mcnamara@ctribune.ie

A class taking part in a study on Pilates at NUIG

Pilates is good for the young and old

We all know exercise is good for us. But as we get older, it seems many of us are exercising less and less. Yet it's when we get older that exercise becomes even more crucial. The loss of both strength and muscle mass occur naturally with increasing age. Muscle strength decreases at a rate of 15% per decade between 60 and 80 years, and 30% per decade after 80 years, whereas muscle mass, at the age of 90, decreases up to 50% in comparison with younger people.

Falls in older adults are a major public health problem, with one out of every three people ages over 65 years falling every year.

Balance disorders also have major impact on the older adults who may as a result reduce their social autonomy and daily activities.

Physical activity and exercise for older adults maintains muscles, preventing pain and joint injuries as well as providing a social outlet.

The heart and stroke charity Croí recently introduced Pilates classes in a bid to get their patients into a regular, beneficial exercise routine.

Pilates was developed by German native Joseph Pilates (1880-1967) in the 1920s. His father was a gymnast and his mother a naturopath and he developed a system of exercises which were intended to strengthen the human mind and body in the belief that mental and physical health were interrelated.

Pilates said that the inspiration for his method came to him during World War One, while he was being held in an internment camp on the Isle of Man. He developed his method for four years on his fellow internees, designing a regime of stretching, strengthening, body alignment and increased core strength.

The levels of Pilates are beginning, intermediate and advanced. The exercises are given in sequences and repetitions. Pilates has six principles to engage in during exercise: control of the mind and body, concentration, centring, flow, breathing and precision.

Pilates works using low muscle contraction impact exercises, intensely strengthening the abdominal muscles. A Pilates routine generally includes exercises that promotes core strength and stability, muscle control and endurance, including exercises that encourage proper posture and movement patterns. It encourages improved balance, flexibility and strength.

The stretches can help elongate muscles and increase range of motion and flexibility.

Abdominal muscles, lower back, hips and all remain contracted and engaged during a Pilates workout. This constant tension helps keep the core muscles lean and build better endurance and strength.

It improves breathing by paying careful attention to breathing patterns which also improves blood circulation in the body.

Pilates makes you more aware of your ability to pull your stomach in and pull your shoulders down for good posture and spinal alignment.

"Every part of the body, from head to toe, gets a workout from Pilates. Your entire musculature is evenly balanced and conditioned, helping you enjoy daily activities and sports with greater ease, better performance and less risk of injury," explains Croí's Edwina Treacy.

Physiotherapist and Pilates instructor, Larissa Donatoni da Silva, has been conducting a study into Pilates and older people at NUIG. Her doctorate is investigating the effectiveness of Pilates in falls prevention in healthy adults over 65 years old. Participants take one-hour classes twice weekly and take tests around physical activity, balance, foot pressure, mobility, gait, cognition and falls.

For a preliminary study, she had 32 participants trying out mat Pilates for the first time, with accessories such as balls and bands. Since last January she is conducting a long-term study involving around 60 people.

"Exercising using Pilates can help reach the goals of increased bone mineral density, muscle resistance, flexibility, stretching, Postural alignment, motor coordination, proprioception, balance, and mobility," she explains.

Larissa Donatoni Da Silva practicing Pilates.

"Older adults may be able to practice traditional Pilates equally as well as younger people with very careful instructions - it is very important to have a qualified instructor."

According to Joseph Pilates, practitioners will feel a difference in ten sessions. In 20 sessions you will see the difference, "and in 30 you will have a new body".

Larissa points to a host of studies which highlight the benefits of Pilates - it has been shown to help prevent coronary heart disease, increase muscular power, reduce the risk of respiratory ailments and improve control of the body.

A 2009 study found it taught people to maintain a correct posture in everyday situations, such as sitting, walking and squatting.

In her native Brazil, Larissa worked at a rehabilitation clinic for six years with orthopedics and post operation recovery and taught mat Pilates since 2008.

She arrived in Galway to pursue a PhD at the Health Science School at NUIG funded by a Brazilian scholarship program called Science Without Border.

"I have always been fascinated about the body and human movements. Introducing Pilates to older adults has been both fascinating and challenging."

■ *Anybody over the age of 65 and in good health who is interested in taking part in the study in 2018 should contact Larissa Donatoni da Silva on laridonatoni@gmail.com.*

Ongoing Pilates for older Adults study - Galway. Advertiser Journal, Life & Style, 23 feb 2017.

February 23 2017

LIFE STYLE

WEIGHTLOSS | DIET | EXERCISE

www.advertiser.

HEALTH & Fitness

NUI Galway recruiting participants for ongoing Pilates study

Study on the efficacy of Pilates in falls prevention

NUI Galway is recruiting participants for a study on the efficacy of Pilates in falls prevention in healthy older adults over 65 years of age. The outcomes assessed will include questionnaires and tests of physical activity, balance, foot pressure, mobility, gait, cognition, and falls.

Pilates consists of six principles to engage during exercise to control the mind and body — control, concentration, centring, flow, breathing, and precision. Pilates works with the deepest muscles and helps to control the posture in many daily activities such as patterns of gait in walking, speed, and mobility.

One hour classes will take place in Áras Moyola twice weekly. There will be a total of 24 sessions for each group for the main study and participants are advised to wear comfortable clothes for exercises.

The study is being conducted by Larissa Donatoni da Silva, an NUI Galway health science PhD, physiotherapist, and Pilates instructor. "Our study is looking at the effect that participating in Pilates has on balance, breathing, stretching, and coordination," she said. "In particular, we are interested in people over 65 years old, who enjoy doing exercises. We want to measure your level of function with questionnaires and tests so that we can compare it with people who are not practising Pilates."

The free Pilates exercise classes will be mat Pilates with accessories including balls and bands. Participants will get a home Pilates exercise programme and a DVD with exercises demonstrated by the Pilates instructor.

Those interested in participating will need to attend one of the initial meetings on Monday February 27 at 1pm or Friday March 3 at 10am in Áras na Mac Léinn at NUI Galway, where Ms da Silva will explain the study.

For more detail or to participate in the study contact Larissa Donatoni da Silva at laridonatoni@ gmail.com or on between 9am a weekdays.

NUI Galway Recruiting Participants for Ongoing Pilates Study. 21 feb 2017. https://www.nuigalway.ie/about-us/news-and-events/news-archive/2017/february2017/nui-galway-recruiting-participants-for-ongoing-pilates-study.html

The efficacy and the benefits of Pilates to the older adults 2017 (Radio Galway Bay - Interview).

Participants Required for Ongoing Study on the Efficacy of Pilates in Falls Prevention. 21 April, 2016.https://www.nuigalway.ie/about-us/news-and events/newsarchive/2016/april2016/participants-required-for-ongoing-study-on-the-efficacy-of-pilates-in-falls-prevention.html

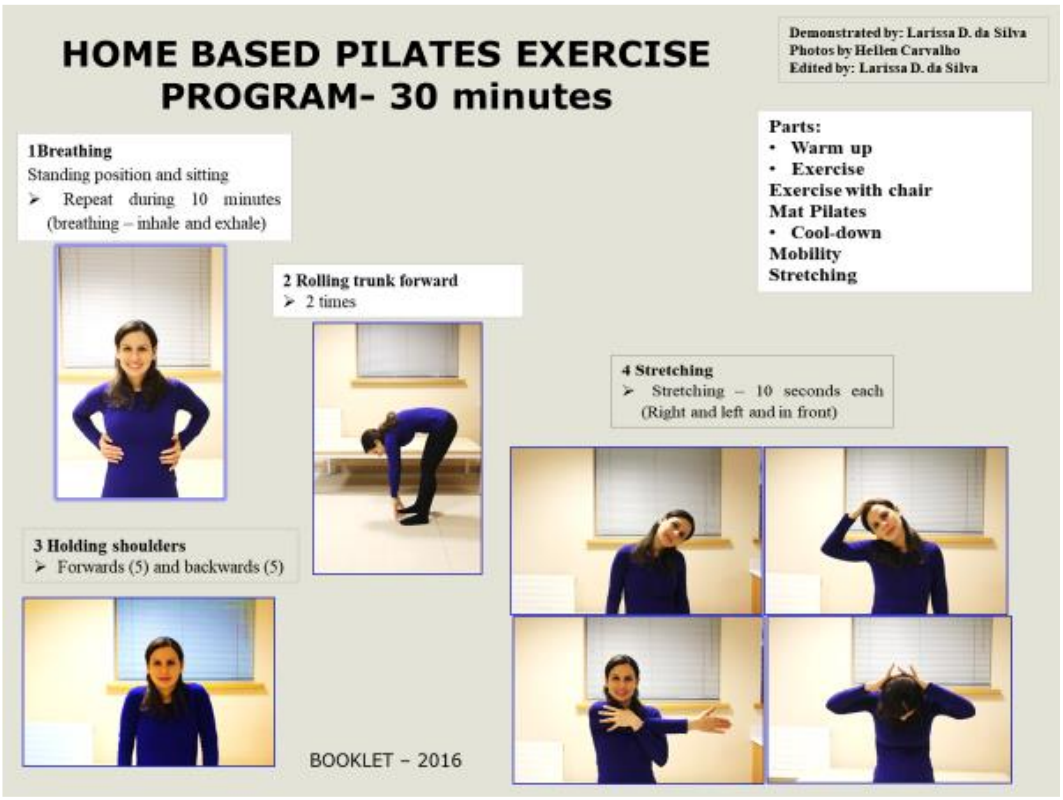
Can Pilates prevent falls in elderly? Life Health & Wellbeing, feb, 2016. https://www.independent.ie/life/health-wellbeing/can-pilates-prevent-falls-in-elderly-34407068.html

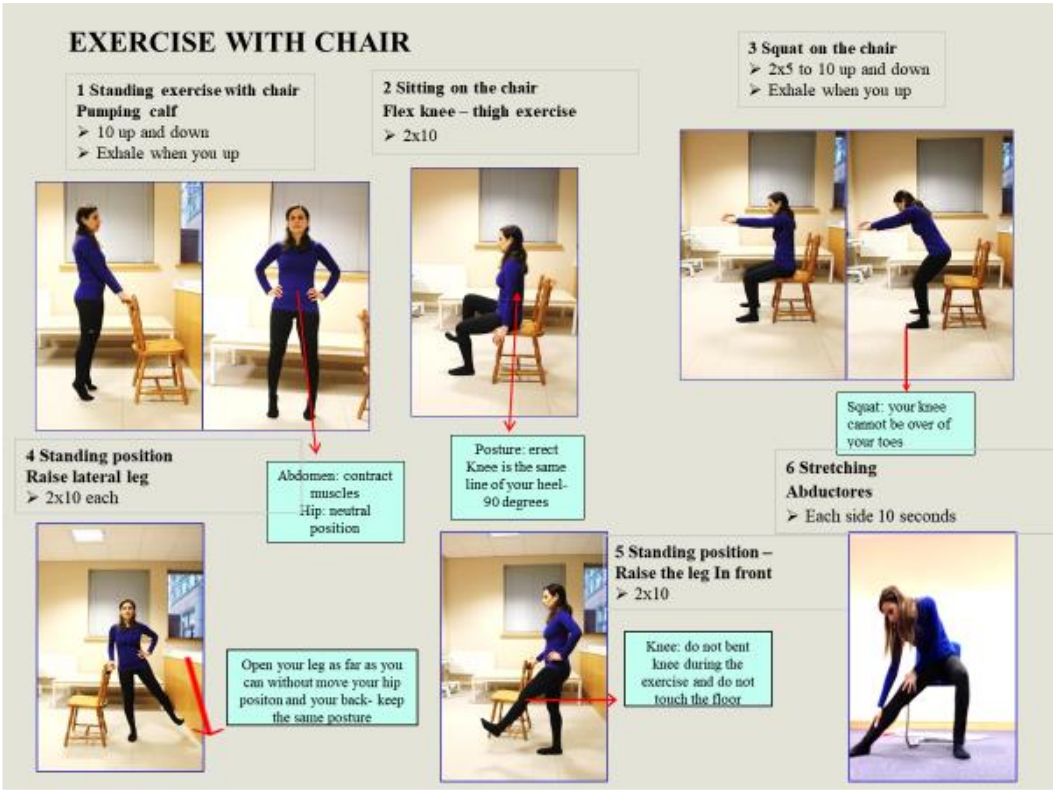
Participants required for study on the efficacy of Pilates in falls prevention. Galway Advertiser, 28 Jan 2016. https://www.advertiser.ie/Galway/article/82375/participantsrequired-for-study-on-the-efficacy-of-pilates-in-falls-prevention

Participants needed for study on falls. Could Pilates help in the prevention? Irish health.com. 26 Jan 2016. http://www.irishhealth.com/article.html?level=4&id=25180

Participants needed for study on falls. 26 jan 2016.
http://newtownpharmacycobh.ie/news-view.php?news_id=1129

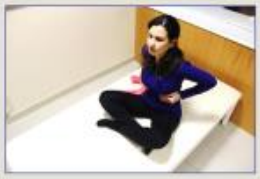
12 Booklet


HOME BASED PILATES EXERCISE PROGRAM- 30 minutes
Demonstrated by: Larissa D. da Silva
Photos by Hellen Carvalho
Edited by: Larissa D. da Silva
Parts:
• Warm up
• Exercise
Exercise with chair
Mat Pilates
• Cool-down
Mobility
Stretching
1Breathing
Standing position and sitting
➢ Repeat during 10 minutes (breathing – inhale and exhale)
2 Rolling trunk forward
➢ 2 times
3 Holding shoulders
➢ Forwards (5) and backwards (5)
4 Stretching
➢ Stretching – 10 seconds each (Right and left and in front)
BOOKLET – 2016


EXERCISE WITH CHAIR
1 Standing exercise with chair
Pumping calf
➢ 10 up and down
➢ Exhale when you up
2 Sitting on the chair
Flex knee – thigh exercise
➢ 2x10
3 Squat on the chair
➢ 2x5 to 10 up and down
➢ Exhale when you up
Squat: your knee cannot be over of your toes
4 Standing position
Raise lateral leg
➢ 2x10 each
Abdomen: contract muscles
Hip: neutral position
Posture: erect
Knee is the same line of your heel- 90 degrees
6 Stretching
Abductores
➢ Each side 10 seconds
Open your leg as far as you can without move your hip positon and your back- keep the same posture
5 Standing position – Raise the leg In front
➢ 2x10
Knee: do not bent knee during the exercise and do not touch the floor

MAT PILATES

1 Breathing sitting
- 10 seconds



2 Stretching (sheet or towel)
- Bent knee hamstring stretch 3x30
- Bent knee hamstring stretch 2x30
- Hip roll 3 times each side

Knee: Attempt to stretching hamstring without bent knee.
Hip: do not up hip of the Mat

- Toes up
- Leg down over the Mat.

3 Bridge with Pillow
Pillow or towel between your knees
- 5 to 10 seconds

Knee: direction of your hell
Hip: direction of your back

4 Bridging
Pumping arms
- 3x10

5 Single leg stretching
- 3x10

Do not move your leg up the knee.
Toes up – move up and down (leg down the knee)

BOOKLET – 2016

6 Bicycle (coordination)
Double leg flexes knee 90 degrees (in the air)
Move your legs like ride a bicycle alternating
- Cycling during 30 seconds forward and 30 seconds Backway

8 Coordination
Engage Right arm and left leg vice-versa
Breathing up limbs exhale
- 3x10

Foot: Just touch the toes on the floor
Knee: 30 to 120 degrees (flex and ext)

7 Double leg straight up
- Fase I and Fase II
- 3x10

Pumping arms (up and down) – 30 degrees- without touch the table

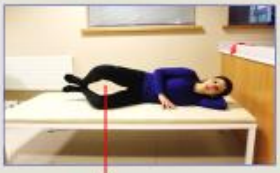
Head: keep your chin close to your chest
Neck: Do not move your neck
Eyes: keep the eyes to your bell

9 Lateral leg
- 3x10

Leg: up and down do not without move your hip
Toes up
Posture straight

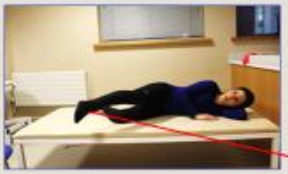
BOOKLET – 2016

10 Oysters
- Fase I and Fase II (heels up)- 3x10



Fase I: heels down on the Mat
Fase II: heels up together and knee on the table

11 Leg sweeps front to back
Up leg stretch and put your feet forward until move the hip
- Repeat 10 times each side (2x)



Foot: move your foot (toes point as you kick a ball) and backward heels.

MOBILITY
1 Rolling like a ball
- Repeat for 5 times

Stretching you knee and try to touch your ankle or toes

MOBILITY
2 Roll up
- Repeat for 5 times

Arms up to the celling

Move your hip the position when your trunk up and down

BOOKLET – 2016

COOL-DOWN

1 Bent knee hamstring stretch
- 30 seconds

2 Straight leg hamstring stretch
Leg forward to the celling and another leg keep your knee flex with the foot on the floor. Pull your leg as close as you can to close to your body
- maintain during 30 seconds.

STRETCHING
1 Child position
- Rest for 30 seconds

2 Supported on the forearms Star
- during 10 seconds

BOOKLET – 2016

REFERENCES
Robinsonlynne Thomsom Gordon; Ref.1999
RodriguezJose, Pilates Marco Zero, 2006.
Eme Cole, 2005
Valeria Figueiredo,2008 (course)
Body controlPilates,2015 (course)

If you have fall during the study design

Name	
Male or Female	
Age	
Group	
Had Falls	No ( ) Yes ( )
Where did you have fall	
Which situation	
Are you were alone	
Did you hurt	
How many times	Once ( ) twice ( ) more than twice ( ),

BOOKLET – 2016

Evaluation for 6 weeks– three times a week during30 MINUTES

1 week

Days-

Day of the week-

2 week

3 week

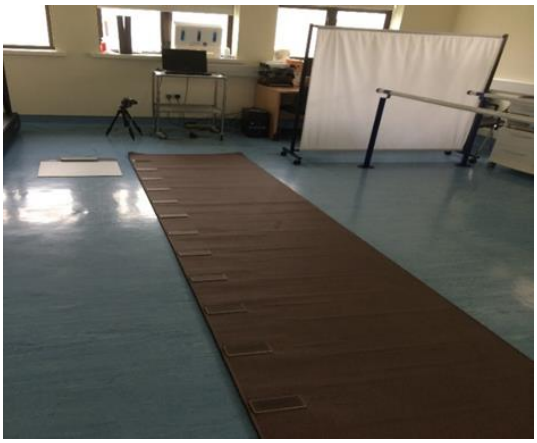
4 week

5 week

6 week

13 Equipments

GAITRite® system



GAITRite® Technical specifications techniques of electronic walkway: is 6 m long with 18,432 pressure sensors, measurement area is 61 cm wide and 488 cm long. Sensors are (48 × 384) and place 27.1 cm on centre. The sampling rate of the system between 32.2 and 38.4 Hz. https://www.gaitrite.com/.

Platform footworkpro

Footwork Technical Specifications: active area: 400x400, sensor Size: 7.6 x 7.6mm, calibration: 100% digital, Plate Thickness: 5mm. Sensor Type Capacitive; pressure range: 10 kpa/1200 kpa, total size: 575 x 450 x 25mm, accuracy Approx.: 5%, Hysteresis: <3%, temperature: -10 + 45-degree C, number sensors: 2,704 (calibrated), connectivity: USB2 (AM3 Professional Pressure Mats-FOOTWORKpro). - http://www.amcube.co.uk

14 Manuscript

Effects of Pilates on the risk of falls, gait, balance and functional mobility in healthy older adults: a randomised controlled trial. Journal of Bodywork and movement of therapies (Elsevier). *Journal of Bodywork and Movement Therapies 2022-02. DOI: 10.1016/j.jbmt.2022.02.020. CONTRIBUTORS: Larissa Donatoni da Silva; Agnes Shiel; Caroline McIntosh*

ABSTRACT

Objective: To investigate the effects of Pilates on falls risk, fear of falling, postural balance, functional mobility, spatiotemporal gait parameters, mobility and physical activity in older adults.

Design: Randomized Controlled Trial (RCT)

Methods: Sixty-one older adults, mean age 70.08 (SD = 5.51) were randomly allocated into a Pilates group (PG, n = 29) or control group (CG, n = 32). Intervention comprised a 12-week Pilates program, with exercises performed twice a week and supplementary exercises at home. The Montreal Cognitive Assessment (MOCA), was used to screen cognition. Primary outcomes: Fear of falling, postural balance (force platform), gait velocity (electronic walkway). Secondary outcomes: Functional mobility, mobility, physical activity, and spatiotemporal parameters of gait. Statistical analysis was carried out using Generalized Estimating Equations (GEE). Covariates were adjusted.

Results: Positive effects were found for time effects: Time Up and Go (TUG), anteroposterior (AP) and mediolateral (ML) directions of balance, cadence, (stance, step and double support time). The step and double support time showed significant differences between the two groups ($p < 0.05$). Interaction between time and groups was found for FRT. Age was a significant factor in TUG, FRT, postural balance for AP under open eyes conditions. Health status was significant for ML in eyes open condition. Gait was significant for age, height and health status.

Conclusion: Effects of 12 weeks of Pilates intervention on functional mobility, mobility, postural balance and spatiotemporal gait parameters were identified. Further trials of a longer duration are warranted to determine the effectiveness of Pilates on falls prevention.

Key-words: Pilates, elderly, fall prevention

INTRODUCTION

Age-related loss of skeletal muscle mass (Tieland et al., 2018), muscle strength or muscle power are frequently observed in older adults and are known to cause limitations in daily mobility and functional capacity (Grimmer et al, 2019). Furthermore, these age-related degenerative changes can impact upon quality of life and physical performance in older adults (Tieland et al., 2018). Advancing age is associated with decreased balance control (Roman-Liu, 2018) as well as deterioration of motor skills, which affects walking ability (Pirker & Katzenschlager, 2017), functional capacity for ability and intensity movements for daily tasks such as walking and climbing stairs (Grimmer et al, 2019). Finally, decreased balance may cause fear of falling, which leads to changes in gait patterns among the older adult population (Verghese et al., 2009; Donoghue et al., 2013; Donath et al., 2014).

A fall is a complicated event that can have implications on a person's wellbeing particularly in the domains of their physical health, mental health and social wellbeing, therefore, a focus on the prevention of falls is crucial (Pin and Spini 2016). A fall occurs when a person has difficulty maintaining their center of gravity (COG) within the base of support by their feet (Roman-Liu, 2018). Most dangerous falls happen when older adults are walking, thus the spatiotemporal parameters of gait are useful for assessing individuals in a clinical setting to identify which older adults are at risk of falls (Mortaza et al., 2014). To establish falls risk Public Health England and the National Falls Prevention Coordination's (2019) recent recommendations include using tests such as Time Up and Go, the 30 second chair rise and the Short-Form Falls Efficacy Scale-International (FES-I) and recording any falls during the previous 12 months. Furthermore, they also recommend a 12-

week follow-up exercise program (whereby the attendance of the participants in class should be more than 75%).

Exercise programs have been found to be effective in reducing the risk and rate of falls (Chang et al., 2004). A recent systematic review and meta -analysis stated that the rate of falls reduced by 39% after exercise balance programs (Sherrington et al, 2017).

Public Health England and The National Falls Prevention Coordination (2019) have recommended that exercises should focus on balance training and must be challenging, including movements that encourage working the center of mass, forming a smaller base of support, and decreasing upper limb support. Including a supplementary home-based exercise (Sherrington et al, 2017). The Physical Activity Guidelines Advisory Committee Report (2008) recommends that people aged 65 years and older should perform moderate intensity aerobic, muscle-strengthening and balance activities for 30 minutes a day, five days per week, or at least 150 minutes per week.

Pilates exercises are useful to help older adults improve their mobility and independence and to decrease the burden of falls. A recent systematic review on the effect of Pilates method on physical fitness in the elderly concluded that there is a need for high quality clinical trials with greater methodological rigor. Specifically, trials that report on under investigated variables including the specific exercises that were performed, intensity, number of repetitions, number of absences and training of the Pilates professional (Pucci et al. 2019). A recent Pilates (RCT) study found improvement in balance confidence, fear of falling and postural stability in older women after twelve weeks of training (Aibar-Almazan et al., 2019). However, in contrast to that, three studies found no improvement in balance

for the Pilates groups after eight weeks (Donath et al., 2016) and twelve weeks of training respectively (Gabizon et al., 2016) and a crossover study found no difference between groups of Pilates and control (Bird et al., 2012).

Previous studies on Pilates have shown efficacy in both the short and long term in decreasing the risk of falls. However, there is still a shortage of studies that evaluate the fear of falling, spatiotemporal parameters of gait and after effects of a Pilates intervention program with supplementary home-based exercise. Thus, this randomized controlled study investigated whether a 12-week Pilates intervention with a supplementary at-home program was effective in reducing falls risk factors in healthy older adults (≥ 65 years). The aim of the study was to identify whether fear of falling, physical activity, postural balance, functional mobility, mobility and spatiotemporal gait parameters were affected. A further aim was to establish whether there was a relationship between fear of falling, physical activity, postural balance, functional mobility, mobility and gait and the covariates of age, health status and height.

METHODS

Study design

This study was a randomized controlled trial (RCT). Participants were randomly allocated into a Pilates group (PG), who practiced Pilates and a control group (CG), who were advised not to undertake additional exercise, over and above their usual routine, during the twelve weeks study period.

The study was advertised on the internet, in local newspapers and on the radio. The study information was also disseminated in retirement communities in Galway city. This study followed the CONSORT statement for a randomized controlled trial

(http://www.consort-statement.org). Participant recruitment took place in January 2017. As more participants were required for the study, additional adverts were included in the local journal and emails were sent to other prospective participants in November 2017. The principal investigator held meetings with those interested in participating at the National University of Ireland (NUI) Galway. The study was granted approval by the NUI Galway Research Ethics Committee (REC)- NUI Galway. The study is registered on clinicaltrials.gov number NCT04343300.

Randomization

Randomization was carried out by the first author using computer-generated random numbers for participant allocation to (PG) and (CG) (https://www.random.org/). This was an open label trial. The allocation sequence was concealed from participants. The PI enrolled and assessed participants sequentially. After participants completed the screening assessments the allocation of participants for the groups was revealed. The groups allocation was open to all.

Participants

In total, 99 people were assessed for eligibility, 61 healthy older adults were eligible to participate in the study and were randomized to the (PG) (n = 29) and the (CG) (n = 32) **(see fig. 1).** Baseline characteristic detail **(see table 1).**

Inclusion criteria:

- healthy older adults ≥ 65 and able to attend the Pilates sessions regularly,
- had no surgery in the past six months and had no restrictions recommended by their General Practitioner.

Exclusion criteria:

- had a MOCA (Nasreddine et al., 2005) score of less than 26,

- had chronic musculoskeletal pain (e.g., chronic back pain) (Barker et al., 2016) and acute inflammation (injury of the knee, hip, or shoulder i.e., tendinitis), had an illness (e.g., unstable blood pressure, myocardial infarction) that could limit the ability to perform safe exercise (Barker et al., 2016),
- had a history of neurological problems, had medical and pharmacologic contraindications to exercise, had vertigo, or already followed a strong exercise routine.

Intervention

The Pilates intervention was a clearly defined study protocol.

Pilates group

Supervised exercises: The Pilates classes lasted twelve weeks; these were supervised classes that took place twice a week for one hour. The classes were divided into a warm-up, mat Pilates with accessories and a cool-down. There were maximum of ten participants included in each class and small items of equipment such as resistance bands, rings, blocks, spiky balls and foam rollers were used. The supervised exercises were evaluated every three weeks for frequency and repetition, focusing on the lower limbs, core and trunk. The exercises involved workouts in sets of two and three and repetitions of ten **(see appendix 1).**

Initially, participants performed the exercises in a standing position. For the breathing exercise, participants held a ring and raised and lowered their heels (leg pumping) and squatted, in line with the six principles of Pilates. In the first week, the participants performed traditional squats and by the fourth week were including a walking squat. At eight weeks, the forward lunge with mini bands was performed

and evaluated. The bands were used to improve resistance. For the first set ten squats, the band was positioned below the knee and for the second ten squats, the band was positioned over the knee.

Some exercises such as the rollover and bicycle needed to be adapted for the older participants. For example, in the rollover exercise a long band was used to facilitate the movement of going up and down during the exercise because the older adults lacked core strength and mobility. In the bicycle exercise the participants kept their hips on the floor. The instructor paid more attention to the older participants when carrying out the exercises with the roller. Finally, the attendance of the participants in each class was recorded.

Unsupervised exercises: The participants were asked to perform supplementary at-home workouts three times a week for 30 minutes using a booklet and video that were provided. The video and booklet introduced the six principles of Pilates, including centering, control, concentration, flow, precision and breathing (Kloubec, 2011) in a warm-up, exercises with a chair, traditional mat Pilates and cool-down exercises **(see appendix 2).**

The Pilates intervention took place at the Áras Moyola building, NUI Galway. The Instructor was a fully qualified physiotherapist and Pilates instructor. The video and booklet were designed by the Pilates instructor. The booklet contains pictures of exercises demonstrated by the instructor. Participants also had access to a home-based Pilates exercises video via a Dropbox link sent to their emails by the Pilates instructor. The instructor also explained and demonstrated the at-home exercises in the video to the participants during the first supervised Pilates class. Participants were also asked to keep falls diaries and give feedback notes and comments. The

participants were asked to give feedback on the same day as the assessments (post-test).

Control group

Participants were recommended to continue their usual routine for twelve weeks. Falls diaries were provided to the participants and after twelve weeks (post-test) the PI assessed the diary. Participants also had a phone number and e-mail to contact the PI.

Outcome Measures

Primary outcomes: Fear of falling, AP-ML directions (postural balance), gait velocity

Secondary outcomes: Functional mobility, mobility, physical activity and spatial (step length and stride length), temporal parameters (swing time, stance time, step time, double support time) of gait.

The instructor collected the pre-test data one week before the start of the intervention period and the post-test one week after the twelve weeks of Pilates.

Each participant was interviewed using questionnaires to assess their concerns about their fear of falling and their level of physical activity. The Falls Efficacy Scale (FES-16-item) score ranges from 16 to 64 (Yardley et al., 2005). The International Physical Activity Questionnaire (IPAQ-short) form questionnaire assesses daily physical activity (Craig et al., 2003). The total scores for walking, moderate and vigorous activity provide the overall level of activity in METs (metabolic equivalent minutes per week), calculated as MET intensity multiplied per minute for each activity during the last seven days (http://www.ipaq.ki.se).The

tool was included to collate data using Excel, which can easily be entered into SPSS (Cheng, 2016).

The Time Up and Go (TUG) test is a reliable, cost-effective, safe and time-efficient way to evaluate overall functional mobility (Kear et al., 2017). Older adults who scored ≥ 13.5 seconds to perform the TUG were classified higher risk of falling, with an overall accuracy prediction rate of 90% (Shumway-Cook, 2000). Participants were asked to perform the TUG and the Functional Reach test (FRT) wearing their own shoes (for each test, participants performed three trials and the average from the three trials comprised the test results). The TUG test evaluated the time that the individual took to get up from a chair, walk three meters, turn around, walk back to the chair and sit down (Podsiadlo & Richardson, 1991). For the FRT test, participants were required to stand next to a wall and put their feet together, without touching the wall. The participants raised one arm by 90 degrees and reached as far forward as possible without taking a step (Duncan et al., 1990). The FRT is used as a measure of balance and fall risk. Normal values in community-dwelling older adults are between 27.2 cm and 28.9 cm (Bohannon et al., 2017).

The balance test was performed with participants standing on a pressure plate (Footwork Pro) with their shoes removed. AM3 Professional Pressure Mats-area: 400x400, sensor Size: 7.6 x 7.6mm, calibration: 100% digital, Plate Thickness: 5mm. First, the participants performed the test with their eyes open with alternate legs raised three times and then with their eyes closed. Their standing position over 30 seconds was recorded for each. Stabilometric parameters calculated the center of pressure (COP) in anteroposterior and mediolateral AP-ML (cm) sway were recorded. Using the GAITRite® pressure-sensitive walkway system participants walked in their own shoes along the walkway 6 m long with 18,432 pressure

sensors, measurement area is 61 cm wide and 488 cm long and an average score was derived for the spatiotemporal parameters of their gait. The following variables were used to predict falls: cadence (step/min), velocity (m/sec), stride length (cm), step length (cm), step time (sec), swing time (sec), stance time (sec) and double support time (sec).

Statistical analysis

The sample size was determined using G*Power software (version 3.1; Universität Düsseldorf, Germany). A power of 0.90 was used (significance level = .05; correlation coefficient = .5; effect size F = 0.28) based on the research data of Mesquita et al. (2015), Aibar-Almazán et al. (2019) and Newell et al. (2012). The total sample size of 36 participants was needed as determined by this calculation. The Cohen's (1988) d test had an effect 0.56, which is considered as medium effect ($0{,}50 \leq d < 0{,}80$).

Data were presented by means and standard deviations (SD), frequencies or percentages of the characteristic details of participants for the Pilates and control groups. The comparison between the control and Pilates groups was tested using the Mann–Whitney U test for age, height, body mass index (BMI) and cognitive ability. A Pearson Chi-square test was performed to test categorical variables for gender, health status related to issues in the past, and falls in the past year (significant at $p < 0.05$).

Data were not normally distributed and non-parametric testing was conducted. The Pilates and control groups and time effects for the pre- and post-tests were analysed using Generalized Estimating Equations (GEE) to compare the Pilates and control groups and time effects for the pre- and post-tests. Bonferroni post-hoc tests were used to identify differences between effects and interactions set at 0.05. Covariates

were adjusted and separated in the model for all outcomes. Results that were not significantly associated with the outcome were excluded from the analyses. The covariates, adjusted in the model on the basis of the characteristic details for all participants analysed, are included in the study. The power of adjusted covariates can be higher than that of unadjusted ones, and the adjustments focus on the treatment effects estimates and an increase in the baseline and results between correlations (Jiang et al., 2015). SPSS 25 was used to analyze the data.

RESULTS

Demographic details

Data on the PG (n = 17) and CG (n = 31) participants were analyzed **(see Table 2).** The participants attended 22 (91.6%.) classes on average. Demographic data in the control group were: age between 65–87 years and a higher percentage of females (83.9%) than males (16.1%); six participants in the control group reported health issues (19.4%) such as (surgery; n=3, replacement; n=2 and pain; n=2), which was more than in the Pilates group (5.9% or one participant). In the Pilates group, individuals were younger than in the control group (aged between 65–79 years) and there was also a higher percentage of females (76.5%) than males (23.5%). There were no significant differences between the control and Pilates groups for any variables ($p > 0.05$).

Falls details

Participants were asked if they had fallen in the past 12 months. In total, *n* (%) =12 (25%) participants had fallen over in previous year. Data was compared between the Pilates group, 3 (17.3%), and the control group, 9 (29%). There were no significant differences between the control and Pilates groups for falls in the past

year, ($p > 0.05$). The control group had higher records of falls. In the diary of falls, five participants reported recurrent falls (16.1%) and 26 (83.9%) participants had had no recurrent falls during the 12-week Pilates program.

Findings

Postural balance improved as a decrease in time score for anteroposterior and mediolateral directions under eyes open condition. There was a statistically significant effect found in time effects for AP, ($p < 0.05$) and ML, ($p < 0.05$). There was no significant difference between the groups, and interaction effects ($p > 0.05$) **(see Table 3).**

After adjusting for age, the result was significant for time effects: AP eyes open condition, ($p = 0.046$) for the pre and post-test, PG= 8.23 (1.01)-6.99 (0.68), and CG= 7.86 (0.65)-6.97 (0.49). There was no significant difference between the groups ($p > 0.05$).

After adjusting for health status, the result was significant for time effects, ML eyes open condition, ($p = 0.043$) for the pre and post-test, PG= 4.27 (0.13)-4.00 (0.12), and CG= 4.20 (0.18)-3.90 (0.11). There was a statistically significant difference between the groups ($p < 0.001$) where the effects on the Control group was higher than in Pilates group.

The FES-16 item questionnaire found a significance in time effects, ($p = 0.004$) adjusting for health status for the pre and post-test, PG=18.03 (0.74)-19.73 (2.05), and CG= 21.62 (1.26)-21.79 (1.11). There was also a statistically significant difference between the groups ($p < 0.001$) which in Pilates group changed score on fear of falling.

The TUG time scores decreased after Pilates training. There was a statistically significant time effect on the pre- and post-test on TUG scores ($p \leq 0.001$). There was no statistically significant difference between the groups and interaction between groups and time ($p > 0.05$) **(see Table 3).**

Adjusting for age reached significance in time effects, ($p < 0.001$) for the pre and post-test, PG= 7.91 (0.18)-7.48 (0.18), and CG= 7.58 (0.12)-7.35 (0.12). There was no significant difference between the groups ($p > 0.05$).

The FRT post-test scores increased after training. There was a statistically significant interaction between groups and time effects ($p < 0.05$). There was no significant difference in time effects and between groups and time effects ($p > 0.05$) **(see Table 3).** Adjusting for age and FRT reached significance in time effects, ($p < 0.001$) for the pre and post-test, PG= 26.10 (0.95)- 28.51 (0.79), and CG= 27.58 (1.06)-27.45 (1.05). There was a statistically significant difference between the groups, ($p= 0.009$) where the effects on the Pilates group were greater than in the Control group.

Spatiotemporal parameters of gait change the time scores as an increase in cadence while a decrease in certain temporal parameters of gait (step, stance and double support time) were observed. A statistically significant time effect was observed for cadence, step, stance and double support time ($p < 0.05$). The same variables also showed a significant difference between group effects ($p < 0.05$). No interaction between groups and time effects for spatiotemporal parameters was found. However, participants improved after Pilates training in their step time and double support time. For the variables of cadence and stance time, the time score was underestimated after Pilates training **(see Table 4).**

The following parameters of gait showed significance after adjusting for health status: velocity, double support time, step length and stride length ($p < 0.05$). There was statistically significant difference between the groups, ($p < 0.001$) for velocity, step length and stride length. Double Support Time showed statistically significant difference between the groups, ($p = 0.013$). After adjusting for age: step length ($p \leq 0.001$), stride length ($p < 0.05$); found no significant difference between the groups ($p > 0.05$). For height: cadence, step time ($p < 0.05$), step length, stride length ($p < 0.001$) and swing time ($p \leq 0.001$). Only for stride length was a significant difference between the groups identified ($p < 0.001$) **(see Table 5).**

DISCUSSION

The 12-week Pilates program had positive effects over time for functional mobility, balance, postural stability and spatiotemporal parameters of gait in healthy people over 65 years of age. The findings also showed an effect between the groups for the spatiotemporal parameters of gait and interactions between the groups for the mobility test. Twelve weeks was not long enough to improve the variables after Pilates training when compared to those for the control group. However, the results were controlled by covariates including age, height and health status to correct the influences. The baseline assessment of the control group identified that they were older, had more health issues and there was a gender imbalance with more females than males. No statistically significant difference between baseline variables were found. It is interesting to highlight that five participants experienced falls in the control group during the study and no falls were reported by individuals in the Pilates group. Ultimately, it seems that this Pilates program may have been effective for the fall risk factor.

Fear of falling

There was no improvement in fear of falling for this population in relation to the FES-16 questionnaire, since the older adults included were physically active. A recent study found that decreased fear of falling and increased confidence in balance are related to increased physical activity and, consequently, decreased risk of falls and social problems in women over 60 after 12 weeks of Pilates (Aibar-Almazán et al., 2019). This study found that the FES questionnaire was significant for health status. The questionnaire seems to be more effective for participants in this population who have limitations, such as health issues. This corroborates another study on Pilates that found an improvement in fear of falling in individuals with chronic lower back pain in the Pilates and physical therapy group and suggests that future studies should include a long-term intervention, a diary to record falls and a measure of balance to analyze participants (Cruz-Diaz et al., 2015).

Stabilometry

This study improved postural stability as a decrease in AP-ML sway for single leg standing with eyes open, which turns less oscillations in the center of mass and improvement in the sensory motor function. The exercise protocol proposed in this study focused on performance in the standing position. The accessories included in the regimen, such as a spiky ball, a roller and the ring and bands, can be used to improve the sensorimotor system, control trunk and core stability and improve muscular strength, respectively. After comparing a Pilates group using a band with a Pilates group that did not use a band, Petrofsky et al. (2005) concluded that Pilates is more effective for balance when including accessories such as resistance bands to increase muscular strength. In contrast, Gabizon et al. (2016) found no improvement in balance control and health status after 12 weeks of mat Pilates with accessories such as a Thera band and a Swiss ball in comparison to a control group

(Pilates exercises were performed in one-hour classes held three times a week). In another study, Donath et al. (2016) compared three groups: traditional balance exercises (n = 16), mat Pilates (n = 17) and a control group (n = 15). They found improvement in balance and trunk strength only in the balance group after eight weeks of training twice a week.

This study found no significant changes in the closed eyes condition, as without visual feedback, postural control changes to improve the somatosensory and vestibular inputs so that more oscillations occur in the center of mass with the result that higher values are observed due to efforts to maintain balance in the single leg test. The explanation for this is that open eyes are stimulated in the first instance in relation to the proprioceptive channel, whereas in the condition of closed eyes, stimulation involves the vestibular channel more compromising the vestibular system (Franzoni et al., 2018). Higher values may show impairment of balance, indicating that individuals were more likely at risk of falling. In this study, the lower values showed improvement under the open eyes condition. There was no statistical significance in time and group effects under the closed eyes condition, although a decrease in all variables of balance was found.

In addition, postural stability was related to age, balance control and decreased fall risk. AP sway with the eyes open was influenced by the aging process, which meant that it was more difficult for the older adults to maintain single leg standing and that they were more afraid to perform the test even with their eyes open. However, ML sway with eyes open was also influenced by health status, as six participants allocated into control group reported pain or other issues in unilateral body training which could influence improvement in the mediolateral direction. Nonetheless,

Pilates was effective in improving balance and decreasing the risk of falls in this population.

Functional mobility and mobility

In general, an improvement in functional mobility was observed in healthy subjects. In contrast, a study of a 12-week Pilates intervention with accessories (such as rubber bands and Swiss balls) showed no improvement in the TUG results for older women after training twice a week (Vieira et al., 2017). However, in another study in which a mat Pilates group focused on trunk core activation, improved TUG scores were observed in Asian participants after training for 12 weeks, three times per week (Hyun et al., 2014). Moreover, mat Pilates without accessories may improve the range of movement in joints and mobility, resulting in better locomotion. TUG performance (the movements of sitting and standing) can be limited by the aging process, as older individuals may walk more slowly and decrease certain movements of the body, such as turning around. The effect of the aging process was corroborated by Kear et al. (2017), who found that TUG was related to age, socioeconomic status and factors such as BMI and multiple comorbidities. This suggests that future research should include a sit-to-stand-test (Bohannon, 2012).

In this study, the FRT showed positive results in relation to an increased score and we also found an interaction between time and groups. The finding was also significant for the age covariate, when the individual performance for a task required moving the trunk forward may indicate a limitation in the range of motion in older adults, which could be improved after Pilates. Johnson et al (2007) believed that after five weeks of Pilates, the subjects had great score in FRT due to improve motor control.

Spatiotemporal parameters of gait

After twelve weeks of Pilates, little change in gait was observed, but there was an increase in cadence as well as a decrease in the following temporal parameters of gait: step, stance and double support time. The spatiotemporal parameters of gait were the only variables in which significant differences were found between the groups in this study. Of the four variables of gait, two (step time and double support time) were found to be significantly different between groups: the improvement was greater after training in the Pilates group than in the control group. However, there was less improvement in the Pilates group for cadence and stance time. It is likely that the individuals in the control group experienced a ceiling effect. With regard to cadence, the control group had higher values at baseline 122.0 step/min than in the Pilates group 117.50 step/min. In addition, the velocity, participants who were allocated to the control group had higher baseline values; for example, a velocity of 145.54 cm/s compared to a velocity of 138.80 cm/s for the Pilates group. Similarity to this, a recent Pilates study suggesting ceiling effects by Choi et al. (2019) found no improvement in temporal parameters and a higher score in cadence parameter, but there was no control group for comparison. In that study, 22 healthy older women improved step and stride length after ten weeks of training (thirty minutes, twice a week) (Choi et al., 2019).

Another study found that the spatiotemporal parameters of gait with higher cadence resulted in shorter periods of gait, as normal walking speed is equal to the product of step length and cadence. If the average step length in walking is related to height, the walking speed will be affected by cadence (Wang et al., 2018). However, cadence increased with speed if older adults walk faster, the patterns of gait change and cadence increases as do step length and stride length (Fukuchi et al., 2019).

This study found that height is an important factor for the variables of gait due to the energy spent during walking (i.e., in the cadence gait variable, older adults have lower cadence and velocity during walking). Another study found that taller individuals have longer legs and walk faster at 80 years old, so there is an association with speed (Elbaz, 2018). This study found that after adjusting the height covariate based on total participants (n = 48) and their baseline details (Mean: 163.26 cm), with 81.3% being women, there was a statistical significance for gait variables such as cadence, step time, step length, stride length and swing time. Other studies have found that stride length is associated with height (MacAulay et al., 2015) and that height is associated with longer stride length and lower cadence (McKay et al., 2017). However, women have a higher cadence than men (Frimenko et al., 2015) and women take more steps than men do, with briefer and closer strides (Ko et al., 2011). Step length has been found to be related to height, independent of sex (Wang et al., 2018).

In this study, the factors of age, height and health status are influenced by step and stride length. The aging process variable was fixed at 70 years and that the height was set at medium for all participants included in the study. Moreover, health status was found to be significant for velocity, step length, stride length and double support time.

The results showed an increased in velocity scores that meant to decrease the risk of falls. As a literature review reported that a self-selected walking speed decreased of 21% between age 20 to 85 years old (Grimmer et al, 2019).

The decrease in double support time corroborates the findings of the study by Scott et al. (2015), whereby non-recurrent fallers improve in the double support phase and that recurrent fallers showed no association in gait parameters over one year

and two months. After two years and eight months, the double support time increased and step length and swing time decreased (Scott et al., 2015).

Limitations

There are several limitations to this study. This study was at risk of bias as it was an unblinded study, loss to follow-up and differential drop-out between the study groups which could affect the results. Intention-to-treat analysis was not carried out.

The participants in the control group could have engaged in exercise routines, which may have affected the outcome measures in those participants. In addition, learning effects for the clinical assessment and the Hawthorne effect may have affected the outcome measures (McCarney et al., 2007).

The intervention program, which included exercises in standing positions and with accessories, may improve muscle strength in the lower limbs and postural control, which could emphasize the results of the ML-AP balance and the spatiotemporal parameters of gait. Moreover, the results were not precise when comparing Pilates with the control group for the ML, cadence and stance time variables.

Furthermore, the instructor adapted the exercises to the individuals who had difficulty performing the exercises. However, the participants preferred to continue with the exercises with minor adaptations; therefore, these individuals were not excluded from the analyses. The analyses were adjusted for the possible covariates influencing the results, which found that health status was significant for gait and balance. Thus, there was no selection bias in the treatment allocation.

Future research should include Pilates exercises over longer periods of intervention, comparison of a home-based exercise group with a supervised group and a follow-up falls prevention study. Researchers should include specific groups for a specific

population, limit the criteria for inclusion of participants and focus on balance and gait training. In addition, future studies should prepare and plan each class in terms of the intensity level of the exercises as this is lacking in the Pilates literature. The instructions should be split to provide a few exercises each week to the participants to avoid them looking ahead and practicing at home. The study suggests that exercising Pilates at home is cost-effective, avoids difficulties with transportation, support from family members or other when is necessary and the cost of the professional. Pilates is easy to practice at home and the individual may fit it into their daily time schedule, following the instructions given by a video and booklet. However, exercises at home have to be checked by a professional frequently, to improve the individual's performance, clarify doubts about exercises and encourage the individual to exercise regularly.

CONCLUSION

A twelve-week Pilates intervention improved functional mobility, mobility, balance and spatiotemporal parameters of gait in healthy older adults. The findings demonstrated an increase in cadence and a decrease in the temporal parameters of gait. The step time and double support time were different between groups. Both parameters of stride length and step length were significant for covariates as age, health status and height in older adults. The effect of the Pilates intervention suggests that long-term intervention in healthy older people after 12 weeks of Pilates with a supplementary home programme still needs further investigation. Further study in this area is warranted.

CLINICAL RELEVANCE

- Falls are a leading cause of morbidity and mortality in older adults

- A 12-week Pilates program, with supplementary home-based exercises, had positive effects on functional mobility, postural balance and spatiotemporal gait parameters which, may reduce the risk of falls.
- Advancing age is associated with decreased balance control and deterioration of motor skills, which affects walking ability. The step time and double support time gait parameters improved after 12 weeks of Pilates.
- Stride length and step length were significant for covariates as age, health status and height in older adults

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