Biomechanical, Physiological and Cognitive Factors in Balance recovery in Older Adults with Knee Osteoarthritis

A thesis submitted in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

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BAppSci (Hons)

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March 2021

Abstract

Worldwide the population is ageing, and with this there is increased cost of age-related conditions to both the medical system and, importantly, the individual. Falls are a concern amongst this demographic due to potential loss of independence, and even death. Knee osteoarthritis (OA) is a common chronic condition in older adults which increases the risk of falling. Despite 40-50% increased falls risk in people with knee OA, little is known about the mechanism of balance recovery in this group and what comprises a stable response to perturbation when simulating falls. There is also little understanding of the influences of pain and executive function on biomechanical responses to perturbation in this group. Importantly, there has been no investigation, to date, for predicting falls in older adults with knee OA using biomechanical parameters related to balance. The aims of this thesis were to investigate (1) the differences in balance response during induced falls in people with knee OA compared to asymptomatic controls in three trial conditions, (2) the relationship between pain and executive function on balance response, (3) the prediction of falls in older adults with knee OA using the biomechanical parameters associated with balance recovery.

Forty-eight older people with knee OA (age average 71.02 ± 6.76 years, BMI average 29.10 ± 4.58 kg/m^2, 54% females) and 15 asymptomatic older adults (age average 72.47 ± 4.81 years, BMI average 26.17 ± 3.06 kg/m^2, 27% females) were recruited. Participants were placed in an induced lean position and were required to recovery balance when released. Spatio-temporal, upper, and lower limb kinematic and kinetic variables were analysed and compared between the two groups in three different trial types: no additional challenge (neither cognitive nor physical dual-task challenge), cognitive dual-task challenge, and physical dual-task challenge. A convenience sample of 24 OA participants was also selected to complete pain questionnaires and executive function assessments. Finally, participants in the convenience sample completed 12 months prospective falls calendars following baseline data collection. Based on reports of falls in this period, the sample was classified into

fallers and non-fallers. The biomechanical measures during balance recovery and other data such as medication usage and patient demographics were used to fit a logistic regression model to predict fallers and non-fallers.

When compared to controls, in all conditions, the OA group showed (1) slower and reduced spatio-temporal responses, (2) less ability to absorb impact forces at the knee, and (3) reduced ability to correct motion of the upper body posture. When compared to no additional challenge trials, in the dual-tasking trials there was (4) slower and smaller spatio-temporal responses and (5) greater knee power absorption, and (6) there was significantly reduced knee motion in the OA group. There was some correlation between unstable balance response and pain, in particular reduced hip flexion angular velocity and increased fear of severe pain (moderate positive, $p = .02$), and increased fear of total pain (moderate positive, $p = .03$). There was no correlation between unstable response and executive function. Finally, high centre of mass velocity and negative (extension) knee moment during balance recovery tasks were found to be good predictors of falls in older adults with knee OA. The relationship between extension knee moment and prediction of falls was stronger in women.

The results from this thesis revealed that, compared to asymptomatic controls, older adults with knee OA took slower and shorter steps, and had a more upright posture following perturbation. Despite the deleterious influence of the spatio-temporal measures arising from the shorter and slower steps, this upright position of the trunk appears to play a part in increasing stability in the OA group via controlling motion of the two thirds of the body's mass. Increased fear and interference from pain was correlated with lower hip flexion angle, which may also play a part in upright posture. Modelling results suggest a combination of upper body kinematics (velocity of centre of mass) and lower limb kinetics (knee extension moment) could be used to predict future falls in older women with knee OA.

Declaration

“I, Calum Sinclair Downie, declare that the PhD thesis entitled “Biomechanical, Physiological and Cognitive Factors in Balance Recovery in Older Adults with Knee Osteoarthritis” is no more than 80,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”.

“I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University’s Higher Degree by Research Policy and Procedures.”

Signature Date 18 March 2021

Dedication

This thesis is dedicated to my daughter, Freyja. May it be an example to you, that anything is possible if you turn your mind to it and keep moving forwards. Do not count the number of times you have fallen baby girl, except to make sure you stand up n + 1.

Acknowledgements

First and foremost, I would like to thank my supervisors, Professors Rezaul Begg and Pazit Levinger. It has been a long, and sometimes fraught, journey since commencing my research experience with you both but from the very start of my honours through to the very last minute of by PhD I know you have had my best interest as your core focus. You have been demanding, but only to ensure that I have learned what I need to learn and for this I cannot thank you enough. I do not know where this path might lead me from here, but the past seven years have been an immeasurable honour for me to learn at your side.

We meet many important people on our path to completing a PhD, and all are etched into my memory for how they have helped. Victoria University laboratory staff, Mr. Ketharasar Ledchumanasarma and Ms. Shannon Barnes for technical assistance. Dr Neil Diamond for the statistical assistance in Chapter 6. For assistance with Visual 3D Dr Hanatsu Nagano. Dr Alessandro Garofolini also for Visual 3D input and so much more, bouncing around ideas, checking my thinking, and assisting in the lab. I want to add my thanks to my editor, Dr Jon Rosalky, for his copy-editing of Chapter 4 of my thesis and his many helpful comments about aspects of English grammar and plain English. Any remaining errors in the text are mine. Jon can be contacted by email at jrosalky@tpg.com.au. If I have missed anyone, it is not through lack of care. I thank you all.

There are three people who will, sadly, never see this work. They all have contributed immeasurably, however. Firstly, my father, William Downie. A possessor of keen intellect, wicked humour, and unsurpassed teaching skill. Whenever asked for assistance in writing the question first asked was always “Where’s your plan?”. Secondly, Dr Russell Best. A man of seemingly infinite patience to explain the maths behind Biomechanics. I still remember the slightest of smiles when I had my “a-ha!” moment in L114. Last, but by no means least, Mr. Robert Stokes. Uncle Rob. An engineer beyond par, who was always willing to listen, guide, and collaborate with me. Gentlemen, thank you. In words only the Scots could conjure …. *Here's tae us; wha's like us? Slàinte Mhath.*

My wife Emily. My love. This tome would not exist without your unerring support. Every day you are by my side, assisting, questioning and challenging, but always supporting. I cannot thank you enough for your unwavering love, good humour, and patience over a difficult period. I have not the words to express how I feel writing this, so I will simply say ∞ and be comforted in knowing you understand.

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List of Abbreviations

ADL – Activities of Daily Living

MOS – Margin of stability

COM – Centre of mass

BOS – Base of support

OA – Osteoarthritis

KAD – Knee alignment device

COM_{vel} – Velocity of centre of mass

ART – Available response time

m/s – Meters per second (velocity)

m/s^2 – Meters per second squared (acceleration)

HIP_{ang} – Hip angle

TRU_{ang} – Trunk angle

RHP – Relative head position

HAT – Head, arms, and torso

EF – Executive Function

TMT – Trail Making Test

Abstracts arising from this thesis

Downie, C. S, Levinger, P and Begg, R. K (2021). Increased falls risk while crossing an obstacle during stability in people with knee osteoarthritis. *Osteoarthritis and Cartilage*, *29*(1), S172-S173. doi: https://doi.org/10.1016/j.joca.2021.02.240

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Chapter 1 – Introduction

The human population, worldwide, is ageing. It is predicted that, compared to the start of the 21st century, the number of people 60 years of age and over will more than double by the mid-century, and more than triple by the end of the century (WHO, 2013). In this same time frame, it is expected that the number of people 80 years of age and over will increase more than seven-fold. The result of ageing is increased risk of disease and decline in both physical function (Kirkwood, 2008; Steves, Spector, & Jackson, 2012), and also cognitive function (Amboni, Barone, & Hausdorff, 2013). Such decline is exacerbated where there are multi-comorbidities, a common occurrence in older adults (van den Akker, Buntinx. F, Metsemakersa, Roosb, & Knottnerus, 1998), such as conditions which affect movement including osteoarthritis.

Osteoarthritis (OA) is the most common disease experienced by older adults (Dieppe & Lohmander, 2005; Heijink et al., 2012; Michael, Schluter-Brust, & Eysel, 2010; Sturnieks et al., 2004) and the knee is the most commonly impacted joint. Knee OA occurs in about 10% of people 60 years of age and over (Buckwalter, Saltzman, & Brown, 2004), with characteristics including pain, disability, muscular atrophy and joint deformity (Alencar et al., 2007; Heijink et al., 2012). These characteristics have a deleterious effect on locomotor function which, in turn, impacts on the individual's independence, and quality of life (Guralnik et al., 2000; Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Guralnik et al., 1994; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). OA also plays a part in increased risk of falling with more than half of people with the disease experiencing a fall (Levinger, Menz, et al., 2011; Williams, Brand, Hill, Hunt, & Moran, 2010) but the exact relationship between increased risk of falls and OA is not yet known (Levinger, Downie, et al., 2016).

In healthy older adults there is reduced muscle strength which leads to shorter steps being taken in an induced forward fall (Karamanidis, Arampatzis, & Mademli, 2008), at slower speed during a rapid stepping test (Medell & Alexander, 2000). The result of these shorter and slower steps is the need to employ a multiple (two or more) step

strategy to recover balance in an induced forwards fall (Barrett, Cronin, Lichtwark, Mills, & Carty, 2012; Carty, Mills, & Barrett, 2011). Further challenging balance recovery ability is the positioning of the upper body. Most of an individual's body mass resides two-thirds of our standing height (Haddad, Rietdyk, Claxton, & Huber, 2013), and the result of this positioning is inherent instability via the inverted pendulum model (Winter, 1995). In essence, while the ankle acts as a pivot the mass of the upper body creates motion. The posture of the upper body is, therefore, also a vital component of balance control and maintaining the centre of mass within the base of support will avoid instability. The velocity of the centre of mass is an important consideration additionally, as higher velocity is also significantly associated with taking multiple steps following perturbation (Carty, Cronin, Lichtwark, Mills, & Barrett, 2012b), a known predictor of falls (Carty et al., 2011).

While research into balance recovery in people with knee OA has been limited, there has been similar links made to instability in this group to that of asymptomatic older adults. This has included shorter and slower steps, and poor strength (Downie, 2014; Levinger, Downie, et al., 2016; Levinger, Nagano, et al., 2016a; Levinger, Nagano, et al., 2016b). While these works addressed the function of the lower limb following perturbation they did not, however, address the role of upper body posture in relation to balance control in older adults with knee OA, nor did they address the impacts of either pain or cognitive function in relation to balance control. Furthermore, while taking slow steps is not only linked to increased falls risk, it has also shown efficacy in predicting falls in otherwise healthy older adults (Cleary & Skornyakov, 2017) as has trunk position (Grabiner et al., 2008), to date, there has not been any studies conducted to predict future falls in older adults with knee OA using biomechanics of stability data.

This thesis addresses the following aims and hypotheses:

Study one (Chapter 4): The effect of Osteoarthritis and dual-tasks on balance recovery from induced leans

Aims: (i) to investigate biomechanical differences in response to induced falls between group (control and OA), trial task (no additional challenge, cognitive dual-task challenge, and physical dual-task challenge), and group by trial task, and ii) to

determine the differences in physical function in people with knee OA compared to age matched controls.

Hypotheses: (i) older adults with knee OA would, across all three trial types, present a more unstable balance recovery performance at foot contact of the first recovery step, than controls. This would manifest itself in higher velocity of centre of mass, shorter step length at lower step velocity, and greater trunk flexion angle, and ii) individuals with OA would demonstrate poor physical function, in particular strength and performance in functional testing.

Study two (Chapter 5): The influences of pain and executive function on stability in older adults with knee Osteoarthritis

Aim: i) to determine the relationship between pain and biomechanical response to an induced fall in older adults with knee OA, and ii) to determine the relationship between executive function and biomechanical response to an induced fall in older adults with knee OA.

Hypotheses: i) higher pain in older adults with knee OA would correlate with unstable balance response, and ii) poorer executive function in older adults with knee OA would correlate with unstable balance response.

Study three (Chapter 6): Predicting falls in older adults with Knee Osteoarthritis

Aim: to determine if falls can be predicted using a combination of measures including balance recovery performance and other data recorded at baseline in older adults with knee OA.

Hypothesis: falls could be predicted in older adults with knee OA, via a combination of biomechanical and other measures.

Chapter 2 – Literature Review

The literature review begins with a discussion into the issues surrounding the ageing population, stability, and falls. Why falling is of such concern, how this relates to those in old age, and the impact of age-related locomotor decline (including osteoarthritis) and the risk of falls resulting from this. The sections following discuss the current literature, including progress made and research gaps, in the field of falls in older adults with knee osteoarthritis.

2.1 The ageing population and falls in older people

2.1.1 The ageing population

While “Population ageing is a triumph of humanity” (WHO, 2002), it is also a very real global challenge. There is projected to be a pronounced worldwide increase in over 60-year-olds, from 841 million in 2013 to 2 billion in 2050 and almost 3 billion by the end of the century. While over 60-year-olds are expected to increase more than three-fold through the 21st century, persons over the age of 80 are expected to increase almost seven-fold in the same period. People in this latter age group number 120 million in 2013, and will grow to an expected 392 million in 2050 and 830 million by 2100 (WHO, 2013). In 2015, only Japan had in excess of 30% of the population aged over 60. By the middle of the century, however, Canada, most of Europe and some Asian countries (including China) will also have populations with one in three persons being over 60. Furthermore, other countries will then have at least one in four persons over 60 including, America, Brazil, Russia and Australia (WHO, 2015). In Australia, the population of those aged over 65 was approximately 3.8 million (15% of the population) in 2017. This number is expected to reach 8.8 million (22% of the population) by 2057, and 12.8 million (25% of the population) by the end of the century (AIHW, 2018). Together with the observed increase in

worldwide life expectancy from the middle of the 20th century to the middle of the 21st century, there comes a co-increase in the physical ageing of the population.

Ageing is damage at the cellular level which leads to reduced physiological function, increased risk of disease and overall decline in physical ability (Kirkwood, 2008; Steves et al., 2012). Such decline can lead to frailty in older adults via demonstration of three or more of five physical manifestations including; reduced grip strength, low energy, slowed gait speed, low physical activity and/or unintended weight loss (Fried et al., 2001). While any, or all, of these expressions may be experienced in age, the encumbrance arising from this will vary widely within individuals (Young, Frick, & Phelan, 2009). The presence of these factors of frailty, in one individual, might not have much influence but could be highly impactful where there are multi-comorbidities present.

Comorbidities are the combined occurrence of one or more disorders either at the same time, or in a contributing sequence (Kessler, 1995). Co-existence of multiple chronic disorders is common older adults (van den Akker et al., 1998), with as much as 80% of the Australian population aged over 65 years old having three or more chronic conditions (Figure 2.1) (ABS, 2018b). These statistics are reflected in other western countries, including both the United States and Canada (Fortin, Bravo, Hudon, Vanasse, & Lapointe, 2005; Wolff, Starfield, & Anderson, 2002). The presence of these co-morbidities will likely place further impost on the individual's function (WHO, 2015). This is particularly so in conditions which affect movement, such as OA, and also in potential negative outcomes of ageing such as falls.

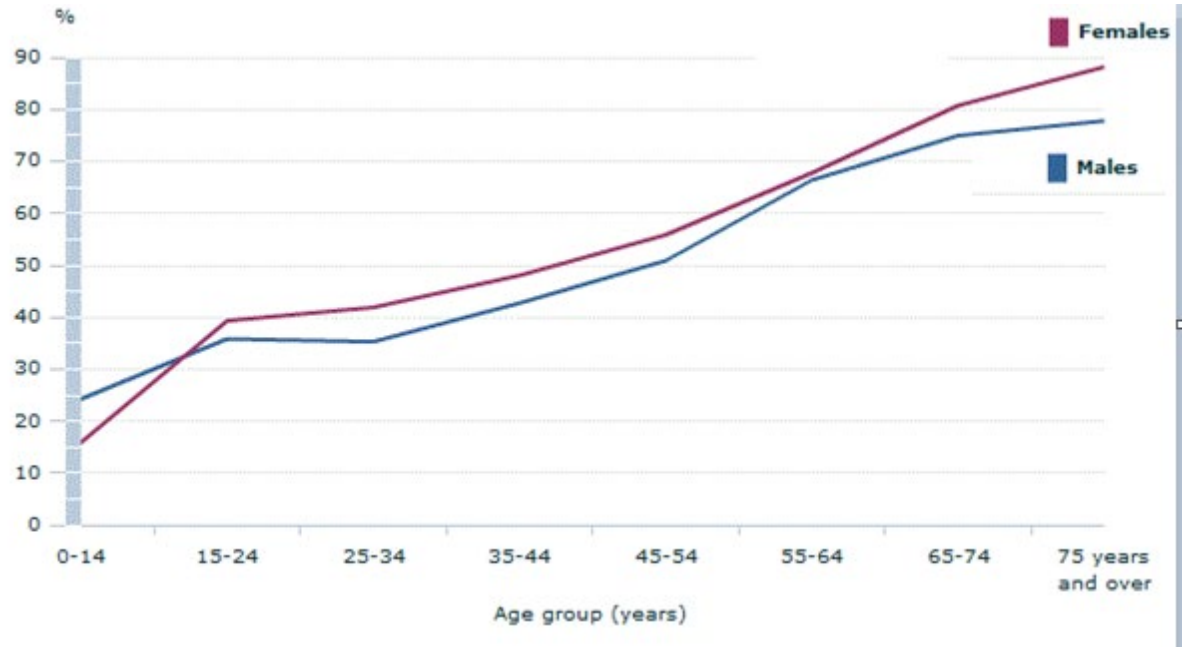


Figure 2.1 - Proportion of persons with one or more chronic conditions in Australia, 2017-18 (adapted from ABS, 2018)

2.1.2 Falls in older people

Before discussing issues around older adults and falls, it is important to first consider how a fall is defined. Generally, there is agreement that a fall is unintended, that there is contact with the ground or other lower level, and that there is no other influencing event such as stroke, or as a result of violence (Masud & Morris, 2001). From a biomechanical point of view, a fall is when the centre of mass comes to lie outside the base of support and where correction does not happen in time to reverse this (Isaacs, 1985), or a new base of support is established in normal gait (Kharb, Saini, Jain, & Dhiman, 2011). For the purpose of this thesis, a fall is defined using the World Health Organisation definition of “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” (WHO, 2007).

Falls are a risk to both morbidity and mortality in older adults (James et al., 2020), presenting a major concern for individuals and heath care systems alike (Landi et al., 2012). It is estimated that, worldwide, 646,000 individuals die each year from falling, while in excess of 37 million falling events annually are severe enough to need

medical attention (WHO, 2018). In Australia, fall-related injury is the 14th highest cause of death with 3,298 deaths due to falls in 2019 (ABS, 2019). The risk of falling and causing injury is known to increase with age (Campbell, Spears, & Borrie, 1990; Rubenstein & Powers, 2002). It is estimated that between 28-35% of those over 65 (Blake, 1988; Campbell, Reinken, Allan, & Martinez, 1981; Prudham & Evans, 1981; Tinetti & Speechley, 1989), and 32-42% for those over 70 (Downton & K., 1991; Stalenhoef, Diederiksb, Knottnerus, Kester, & Creboldera, 2002; Tinetti, Speechley, & Ginter, 1988) fall each year. In Australia, it was estimated that 111,222 people over the age of 65 were hospitalised as a result of a fall in 2014-15, accounting for 2.7% of all hospital stay separations in this demographic (AIHW: Pointer, 2018).

Risk factors for falls can be categorised as behavioural, biological, socioeconomic, or environmental (Landi et al., 2012; Panel on Prevention of Falls in Older Persons & British Geriatrics, 2011). Behavioural factors include intrinsic, and modifiable measures including, abuse of medications and alcohol, lack of exercise and poor footwear. Biological factors include intrinsic, but unavoidable measures including, age, gender, chronic illness and decline in physical or cognitive ability. Environmental factors are extrinsic and include poor building design, floor coverings (eg slippery floors or loose rugs), poor lighting and damaged footpaths. Finally, socioeconomic risk factors include low education and income, and limited access to health, social and community support. This combination of factors increases the risk of falling in this population, when compared to younger adults, and creates a major impact on both the individual, and the health care system charged with caring for the faller.

2.1.3 The impact of falling on the individual, and on the burden on the health care system

The impact of falling is endured both by the health care system, and the individual who falls. For the former, this impact is financial, while in the latter there is a personal cost associated with falling.

The cost of falling on the health care system is aptly demonstrated with more than half of all injury related hospital admissions arising from falls (Scott, 2005). Data

collected from Australia in 2014-15 showed that 111,222 over 65-year-olds were hospitalised as a result of falls, leading to 1.5 million days of care over that period, with each stay being approximately 13 days (AIHW: Pointer, 2018). With the expected increase in the older adult population through the first half of this century, it is estimated that the number of hospital bed days per year arising from falls related injury will double (ANZFPS, 2020). In total, the expected cost of falls in older adults by 2051 will be AUD$1.4 Billion (ANZFPS, 2020). For the individual, regardless of acute injury, the impact of falling can lead to poor response to perturbation and apprehension about movement (Mathon et al., 2017). Furthermore, the faller can also be at increased risk of bone fracture and can perform poorly on tests of function such as the Timed Up and Go (Mathon et al., 2017). Vascular dementia, in particular, may impact on the ability for the individual to avoid a fall through the influence on planning and judgement arising from poor cerebral blood flow.

Almost half of older adults who fall report fear of falls, and about 25% will limit other activities in an attempt to avoid further falling (ANZFPS, 2020). This curtailing of activity can lead to further disability, reduced mobility and can mean increased levels of dependence and potential institutionalisation (ANZFPS, 2020). Alarmingly, where hip fracture occurs during a fall, 20% of this group die within a year (Zuckerman, 1996). From a mortality perspective, falls are the single greatest cause of death arising from injury in over 75-year-olds (Lockhart, Woldstad, & Smith, 2003).

2.2 Knee Osteoarthritis

Osteoarthritis (OA) is the most common disabling joint disease in the world (Sandell, 2012), with half of the global population aged over 65 suffering the condition (Bijlsma, Berenbaum, & Lafeber, 2011; Khalaj, Osman, Mokhtar, Meddikhani, & Abas, 2014). In Australia, OA is the most common form of arthritis effecting 9.3% (2.2 million) of the entire population (ABS, 2018a), and 20% of adults over the age of 45 (AIHW, 2020). Overall, 36% of Australians over 75 experience OA with women more likely to have the condition than men (10.2% v 6.1%) (AIHW, 2020).

OA is illustrated by the deterioration of the articular cartilage at end of bones which leads to bone contact, pain, swelling and reduced range of motion (AIHW, 2020). In the case of knee OA, it is characterised by the narrowing of the space in the medial and lateral tibiofemoral joints (Figure 2.2), formation of osteophytes (bone spurs), sclerosis (structural stiffening) and joint deformity. The knee is the most common site of symptomatic OA in the body through loading of the anterioposterior and mediolateral regions of the menisci (Vincent, Conrad, Fregly, & Vincent, 2012). This may be a result of the mechanics of the medial and lateral tibiofemoral joints and patterns of load in gait, specifically where there is disruption to this loading via mechanisms such as trauma and weight gain (Vincent et al., 2012). This disruption may manifest itself in cartilage degeneration and a reduction in regional thickness of the menisci (Andriacchi, Koo, & Scanlan, 2009).

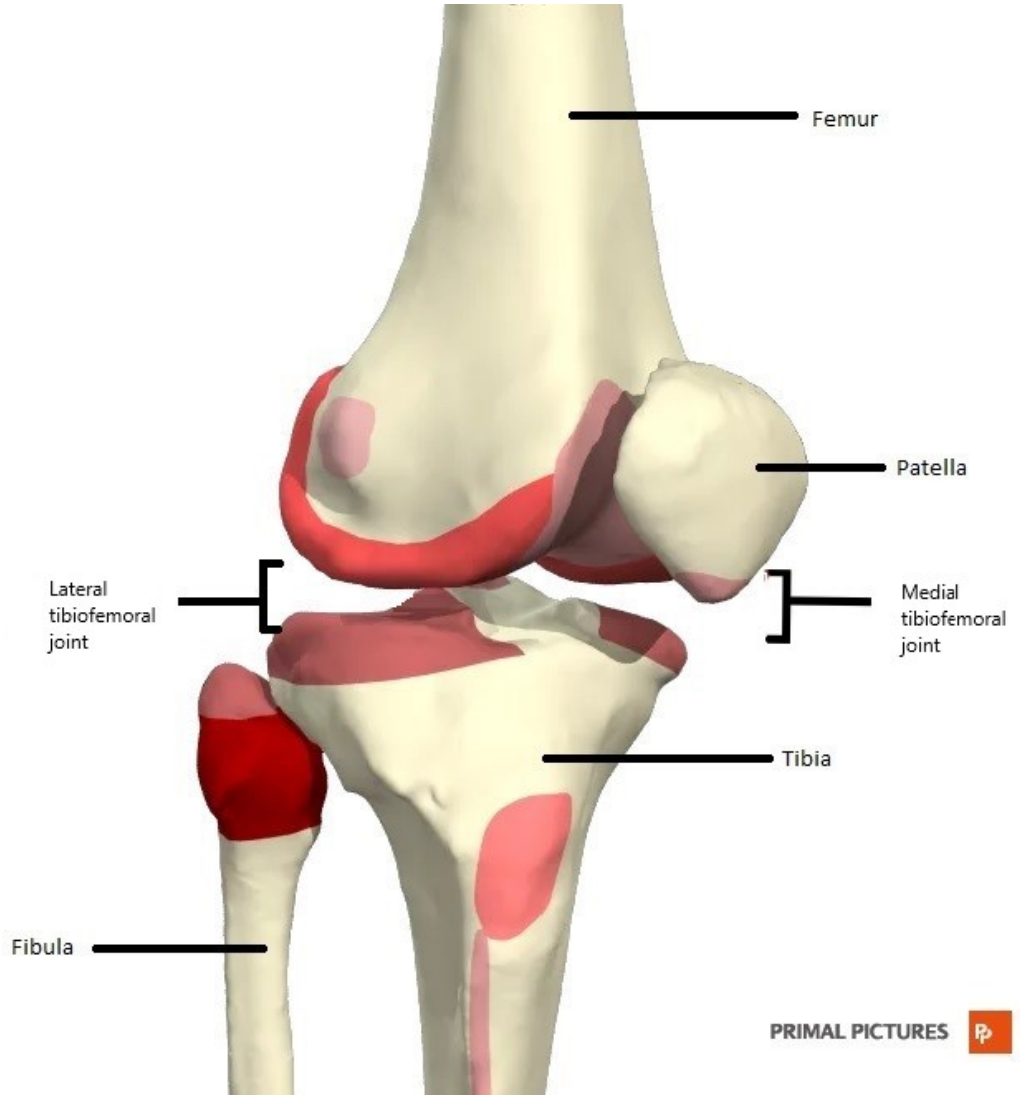


Figure 2.2 – The medial and lateral tibiofemoral joints (adapted from Primal Pictures, 2019), 3D anatomy images copyright of Primal Pictures www.primalpictures.com

OA is commonly thought to be related to both modifiable and non-modifiable factors (Johnson & Hunter, 2014), including:

- modifiable local risk factors (related to the joint itself) including strength, activity, joint injury and alignment and inequality in leg length,
- modifiable systemic risk factors (related to individual predisposition) including obesity, diet, and bone metabolism, and
- non-modifiable systemic risk factors (also related to individual predisposition) including age, gender, genetics, and ethnicity

Increased risk of onset of OA can, therefore, be viewed as either overall predisposition or joint specific predisposition (Johnson & Hunter, 2014). As we age, there is associated degradation of the articular cartilage which may explain the connection to OA but does not explain the other influences. Women appear more impacted by OA, particularly after the age of 60, without any clear causation (Cho, Chang, Yoo, Kim, & Kim, 2010). There is also a genetic component, with heredity being linked to onset of OA more likely in those whose family had history of the disease (Sandell, 2012). Once again, there is no clear connection to explain this, as there appear to be many different processes at play including inherited susceptibility to OA itself, altered mechanical loading, injury, or genetic influence (Sandell, 2012).

The mechanisms for onset, and progression of OA, would appear to depend largely on the stage of life in which the disease presents (Figure 2.3) (Sandell, 2012). While the combination of modifiable factors, including trauma and obesity, and non-modifiable factors, including genetics and ageing, does not change, their relative contributions do. In early-onset there appears a greater genetic component, in mid-onset it is more environmental and in late-onset the mechanism is more age related.

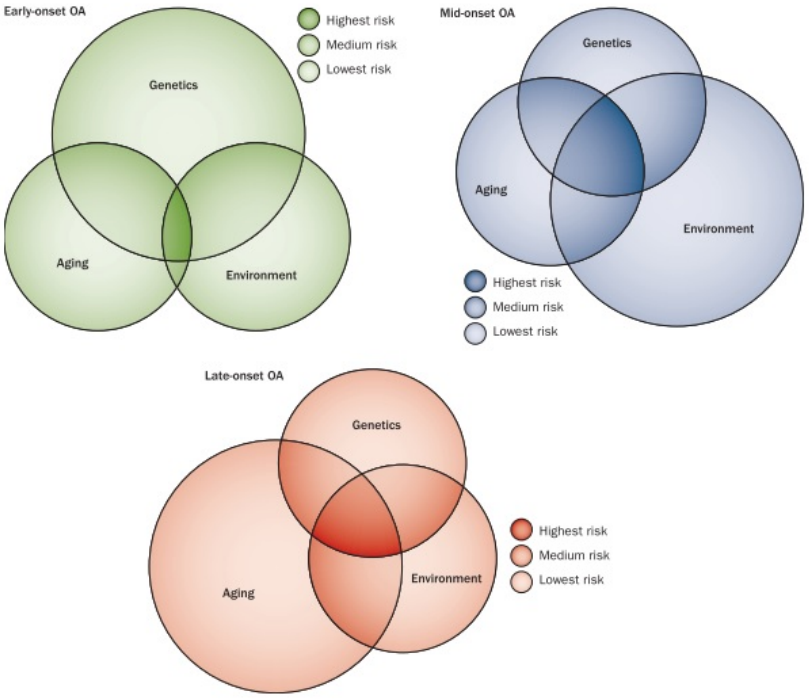


Figure 2.3 - Risk factors for onset (early, mid, and late) and progression of OA (adapted from Sandell, 2012)

While the aetiology is multifactorial, OA is seen as a predominantly age-related disease (Li, Wei, Zhou, & Wei, 2013; Sandell, 2012) however a number of risk factors have been identified that explain why not every older adult suffers from the condition. Though the common experience is degeneration of the Tibiofemoral joint arising from inflammatory responses (Sandell, 2012).

2.3 Biomechanics of balance, stability, falls and locomotion in older adults

2.3.1 Defining balance and stability

The terms stability and balance are commonly used in biomechanical research, without any clear and agreed definition of either. From a kinetic perspective, the concept of balance could be viewed as the net forces acting on the body being zero (Pollock, Durward, Rowe, & Paul, 2000). This description assumes application of Newton's first law, as the inertia of the centre of mass must be overcome if the individual is to avoid a fall. This is a problematic definition, as it accepts that all forces, in all directions, are exactly equal. This cannot be supposed within human movement given the complexities of both quiet stance and gait in bipedal organisms with multiple articulated segments. Movement in gait, and during a fall, involves a great degree of motion and, in using this definition, the individual would be assumed to be unbalanced as the centre of mass is always outside the base of support at certain times within the movement. This leads to another view of balance, that being the ability to avoid a fall, related to both inertia and the properties of body segments (Winter, 1995). This latter definition provides a clear connection to the movement of an individual and leads to consideration of the concept of stability.

Stability, assuming the definition of balance as being a factor of inertia (as discussed above), would therefore be the properties of the individual to resist a change in position and to maintain the centre of mass within the base of support (Pollock et al., 2000). Stability also affords consideration of the individual in motion where the centre of mass position will be either at, or outside, the boundaries of the base of support in order to initiate/continue movement. In order to explain the concept of stability, particularly in motion, one would need to also discuss the posture of the individual at the time of the movement. As a definition, posture refers to the positioning of a body segment relative to the gravitation vector, or the line from the position of the centre of mass directly to the ground (Winter, 1995). This definition allows us to better understand the issues around stability. In human movement there is a noted challenge in balance, through both bipedal stance and the fact that locomotion involves uniped stance (Winter, 1995). As most of our mass resides two-thirds of our

height above ground we are, therefore, unstable by definition (Haddad et al., 2013) and it is the posture of the individual, and the ability to change that posture, which would then have a great bearing on reducing this instability. Ultimately, postural control leads to centre of mass control and keeping its position within the base of support (Haddad et al., 2013).

As per the above definitions of balance and stability, avoiding a fall would mean that the individual is balanced. Contrary to this, however, the discussion around falls uses terms such as ‘balance recovery‘ (Aftab, Robert, & Wieber, 2012, 2016; Carty, Cronin, Lichtwark, Mills, & Barrett, 2012a; Carty et al., 2011; Do, Breniere, & Brenguier, 1982; Downie, 2014; Graham, Carty, Lloyd, & Barrett, 2015; Hsiao & Robinovitch, 1999; Maki, Edmondstone, et al., 2001; Maki & McIlroy, 2006) to describe the action that avoids a fall. Throughout this thesis, however, the Winter (1995b) definitions will be used. In short, individuals will be either; balanced, and therefore stable, or they will be unbalanced, and therefore unstable. A stable response to an induced lean will involve the taking of step(s) before cessation of movement with the centre of mass residing within the newly established base of support (where the individual would not fall in a real-world situation). An unstable response to an induced lean would involve the taking of multiple steps without ceasing movement, nor having the centre of mass residing within an established base of support, until the point of controlling anterior movement via the full-body harness (where the individual would be assumed to fall in a real-world situation).

2.3.2 The biomechanics of stability in falls

The challenge to stability is multifaceted, involving several biomechanical factors, without considering influence of vision and the vestibular apparatus. With respect to the biomechanics of falls, both the upper and lower body have a role to play in maintaining stability. With respect to the lower body, the role of the swing leg is to create a long and quick step to extend the base of support so that the centre of mass position remains within its boundaries. It also must, on landing, produce a ground reaction force of enough magnitude to overcome the anterior forces of the falling body (Mathiyakom & McNitt-Gray, 2008). It is also necessary for the lower limbs to

have eccentric strength enough to absorb the force created by the mass of the body's anterior motion during a fall (Levinger, Menz, et al., 2011). With respect to the upper body, the trunk, in particular, has a large mass compared to the other body segments and therefore has the potential to negatively influence the individual's stability (Arampatzis, Karamanidis, & Mademli, 2008; Carty, Cronin, et al., 2012b; Carty et al., 2011; Grabiner et al., 2008; Grabiner, Feuerbach, & Jahnigen, 1996; Pavol, Owings, Foley, & Grabiner, 2001; Troy, Donovan, Marone, Bareither, & Grabiner, 2008). The mass of the trunk means that two thirds of the body's total mass lies at a position of approximately two-thirds of our height above ground (Winter, 1995) and, when projected anteriorly, would likely cause the rest of the body to follow, thus increasing the propensity to fall when unstable. This is particularly so in the case of trips (Grabiner et al., 1996; Pavol et al., 2001).

Pavol and colleagues (2001) discuss the concept of head-arms-torso (HAT) positioning in a fall. This is a central point of falls research, as the HAT position, and therefore the positioning of the majority of a human's mass (Winter, 1995), can dictate the response available when unstable. Where there is a net anterior angular momentum of the upper body (Winter, Prince, Frank, Powell, & Zabjek, 1996) and, when the margin of stability is low it would seem logical that the individual would find it difficult to control the motion and positioning of the HAT to successfully avoid a fall.

2.3.3 The biomechanical response to losing stability

During a fall, there is a requirement for the neuro-motor system to "select and execute postural corrections including mechanisms responsible for the control of dynamic stability" (Karamanidis et al., 2008). The taking of a step, or grasping with the upper limb, are movements chosen by individuals during a fall. The selection of these choices appear to be initiated early in the fall, well before the centre of mass nears the boundary of the base of support (Maki & McIlroy, 1997, 2006). These response choices arise from a combination of both reactive and predictive strategies, that are respectively compensatory or anticipatory in nature and, when falling, it would appear that the selected stratagem errs more to the reactive (Maki & McIlroy, 1997, 1999). This compensatory strategy involves movement of the lower limb in

order to extend the base of support, thus continuing to envelop the centre of mass as it moves anteriorly. Maki and McIlroy (1997) also noted that, in 32%-45% of falls or near falls, individuals initiate a reactive stepping response even where there is no need to move limbs in order to control balance (Maki, Whitelaw, & McIlroy, 1993; McIlroy & Maki, 1993, 1995). While the employment of a compensatory step is necessitated in some cases to avoid a fall, there are some situations where no step is needed even though it is taken. Perhaps this is a result of the postural influence of the upper body, or as a result of a learned response to falling, though this is not discussed in the Maki and McIlroy works. Early balance recovery research by McIlroy and Maki (1996) did, however, identify two stepping responses to perturbation, single and multiple. In the former, the subjects took only one step and were stable, or took multiple steps and were unstable and such a response is associated with falls risk (Carty, Barrett, Cronin, Lichtwark, & Mills, 2012; Carty et al., 2011; Maki & McIlroy, 1997, 1998).

2.3.4 The influence of dual tasking on falls

Two simultaneously performed tasks interfere with cerebral resources, and the change in performance has been referred to as dual-task cost (Montero-Odasso, Muir, & Speechley, 2012). Such a cost affects trunk motion in healthy older adults, via slowed attenuation of movement (Doi, Asai, Hirata, & Ando, 2011).

The arguments in favour of increased falls risk as result of dual-task cost have centred on how such a cost impacts on stride variability in gait (Hausdorff & Yogev, 2006; Szturm et al., 2013) and, in particular, the idea that a person challenged by the cost (Beauchet et al., 2009; Hausdorff & Yogev, 2006). There has also been an argued link between control of posture and attentional demands in older adults, where dual task cost has been demonstrated to increase variability in stability (Woollacott & Shumway-Cook, 2002).

2.3.5 Effect of obstacle crossing on falls

Poor stability or contact when crossing an obstacle is one the of most commonly reported causes of falls in older adults (Blake, 1988; Overstall, Exton-Smith, Imrns, & Johnson, 1977; Tinetti & Speechley, 1989), occurring in between 30-50% of cases (Tang & Woollacott, 1998). Regardless of the strategy employed by the individual to recover balance, the aim is to control anterior rotation of the trunk, and establish a new base of support (Grabiner, Koh, Lundin, & Jahnigen, 1993).

During obstacle crossing, older adults demonstrate less toe clearance at the obstacle than noted in younger counterparts (Begg & Sparrow, 2006). This would appear to be because older adults employ conservative approaches to obstacle crossing, including slowed step velocity, shorter step length and width, and are also more likely to touch the obstacle with their foot than younger adults (Chen, Ashton-Miller, Alexander, & Schultz, 1991; Chen, Ashton-Miller, Alexander, & Shultz, 1994). Where there is a lower limb joint condition, such as knee OA, participants with pain have been shown to be capable of avoiding a virtual obstacle and there is a linear relationship between pain and avoidance, with around one third of the decreased success rate attributable to increased pain (Pandya, Draganich, Mauer, Piotrowski, & Pottenger, 2005). Furthermore, one might expect greater success in the non-affected limb, but this was not seen. There appears to be three distinct falls groups from an induced trip in older adults (Pavol et al., 2001), those who fell; during the step (prior to completing a recovery step), after the step (after completing a recovery step, but unable to control further steps) and elevating (a mix of during and after step responders whose velocity required several steps). Pavol and colleagues (2001) discussed the significance of HAT positioning in falls in that a more anterior position of the mass of the upper body leads to greater potential of falling.

Given the relative importance of the location of the upper body, crossing an obstacle with a net forwards HAT position is likely to place the individual at greater risk of falling via the motion of the upper body. To date, there has been no research addressing this positioning within the base of support, when crossing an obstacle, in older adults with joint problems such as knee OA.

2.4 Locomotor decline in older adults and the influence on balance recovery and falls

Loss of locomotor function associated with age is a critical factor for independence, falls risk and lower quality of life (Guralnik et al., 2000; Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Guralnik et al., 1994; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). There are several locomotor related characteristics that delineate older and younger adults. During locomotion, older adults have a slower pace, shorter step length and a wider base of support (Lockhart et al., 2003). The resultant influence on gait cycle is longer stance, or double support time (Winter & Scott, 1991). Lockhart (2003) suggests that this influence results in a more stable, and therefore safer, gait pattern for the older adult. However, when perturbed, elements such as shorter steps increase likelihood for the need to take multiple steps to control anterior motion during induced falls, a known factor for increased falls risk (Carty et al., 2011). As the major risk factors for falls in older adults include impairment to both gait and balance (Ambrose, Paul, & Hausdorff, 2013) it is important to consider these influences on falls in this population, in particular the influences of both balance and strength impairment.

2.4.1 Loss of balance in older adulthood

Balance in older adults deteriorates when compared to younger adults (Mackey & Robinovitch, 2006; Pijnappels, Bobbert, & van Dieen, 2005a, 2005b) partly as a result of lower muscle strength and increased tendon stiffness (Karamanidis et al., 2008). During recovery from an induced fall the resulting output includes shorter step length, leading to a lesser increase in the base of support and a decreased margin of stability (Karamanidis et al., 2008). This lack of an anterior shift in the base of support is exacerbated by the reduced step speed also noted in older adults (Luchies et al., 2002; Medell & Alexander, 2000). These challenges to balance control may result in the need to use multiple steps to cease anterior movement during a fall (Carty et al., 2011; McIlroy & Maki, 1996), a known predictor of falls

(Carty et al., 2011). The older adult, in this scenario, would then be described as being unstable and at greater risk of falling.

2.4.1.1 How does balance impairment increase falls risk?

Falls can begin with a loss of stability from either anterior or posterior perturbation (Carty et al., 2011) requiring the individual to take action in order to avoid a fall. While risk factors for falls are, by nature, multifactorial, there are several individual factors that may predispose an older individual to a risk of falling. These factors include dementia, visual impairment, dysfunction within the neuromuscular apparatus (Tinetti et al., 1988), as well as abnormalities in gait and balance (Overstall et al., 1977; Tinetti, Williams, & Mayewski, 1986; Wolfson, Whipple, Amerman, & Kleinberg, 1986). Of all the factors leading to a fall, poor balance appears to be the leading cause (Cripps & Carman, 2001) and is strongly linked to OA via clinical testing of static postural sway (Hinman, Bennell, Metcalf, & Crossley, 2002).

The prevalence for older adults taking multiple steps during falls recovery is well documented (Carty, Barrett, et al., 2012; Carty, Cronin, et al., 2012b; Carty et al., 2015; Downie, 2014; Levinger, Begg, et al., 2017b; Levinger, Downie, et al., 2016; Levinger, Nagano, et al., 2016b; Luchies, Alexander, Schultz, & Ashton-Miller, 1994; Maki & McIlroy, 1997, 2006; McIlroy & Maki, 1996; Nagano, Levinger, Downie, Hayes, & Begg, 2015b), but is not necessarily clearly linked with poor stability. The taking of multiple steps when not needed would appear to be a more conservative approach allowing for more opportunity to control centre of mass position (Luchies et al., 1994). While this may be the case, the inability to recover from a fall in a single step is predictive of future falls (Maki, Edmondstone, et al., 2001). This is because the individual cannot maintain the centre of mass within the base of support, and nor can they maintain stability (Carty, Cronin, et al., 2012b; Maki & McIlroy, 1999).

2.4.2 Loss of strength in older adulthood

Alongside the influences of other disease, the normal influence of ageing on the musculoskeletal system must be considered when investigating falls in older adults. The European Working Group on Sarcopenia in Older People has identified several mechanisms involved in the progression of the disease including changes in protein synthesis and proteolysis (protein breakdown), neuromuscular degeneration and reduction in muscle fat content. The progression of this degradation stages from pre-sarcopenic, identified by loss of muscle mass, to sarcopenic and then to severely sarcopenic, both identified by progressive loss of muscle mass and strength or performance. Importantly, Sarcopenia can be seen as a primary (ie age related) condition where no other cause of loss is identified, or can be secondary when another cause is present, such as OA (Cruz-Jentoft et al., 2010). While the condition, like many others related to ageing, is characteristically variable in both onset and progression, Sarcopenia is distinguished by loss of muscle mass and strength and is observable through a reduction in physical performance (Landi et al., 2012). Furthermore, the link between the elements of Sarcopenia appear to be gender related. Loss of muscle mass is a cause of concern more in men, with women appearing to be more impacted via the loss of function (Scott et al., 2014). Having said this, Sarcopenia increases the risk of falling in all genders regardless of age and other confounding factors (Landi et al., 2012; Tanimoto et al., 2014).

2.5 Locomotor decline in older adults with knee osteoarthritis and the associated influence on stability and falls

The health of the musculoskeletal system is paramount for the individual's ability to move and maintain independence throughout the lifespan (Briggs et al., 2016). Of the most common chronic musculoskeletal conditions impacting older adults, bone disease (OA and Osteoporosis) (Leveille, 2004), as well as rheumatoid arthritis, have been linked with increased frailty and high mortality rates compared to age-matched peers (Briggs et al., 2016; Marzetti et al., 2017).

2.5.1 Falls risk in older adults with knee osteoarthritis

Arthritis of any type is related to higher relative risk of falls than either age, or cognitive function individually (Arnold & Gyurcsik, 2012) with reported falls rates from at least a 40% likelihood and as high as 64% (Brand, Aw, Lowe, & Morton, 2005; Sturnieks et al., 2004; Williams et al., 2010). Compared to community-dwelling older adults without arthritis, this rate of falling is both higher in those with arthritic conditions and the average age of fallers lower (Brand et al., 2005). These figures are related to all forms of arthritis and, in OA specifically, there are more reported falls with an increased risk of 40-50% (Brand et al., 2005; Gillespie et al., 2003; Hoops, Rosenblatt, Hurt, Crenshaw, & Grabiner, 2012; Levinger, Menz, et al., 2011; Williams et al., 2010). While this would appear to present a link between OA and falls the relationship is, to date, not completely clear (Levinger, Downie, et al., 2016). It has been observed, for example, that there is a reduction in falls risk arising from hip OA (Arden et al., 1999), and that OA was independently associated with multiple falls in women (Muraki et al., 2011). Such discrepancies may be associated with variation in both progression of the disease within the samples, as well as a lack of single diagnoses of OA (self-diagnosis or clinical examination (Arden et al., 1999; Brand et al., 2005). Regardless, there appears increased risk with multiple joint involvement, especially of the knee and the hip (Doré et al., 2015). It would appear, then, that while there is evidence for a connection between OA and falls, but no clear

link between falls and the symptoms of OA including poor balance, strength reduction and pain (Manlapaz, Sole, Jayakaran, & Chapple, 2019).

2.5.2 Impaired balance in knee osteoarthritis and risk of falls

Balance impairment in older adults with knee OA has been demonstrated via increased sway (Hassan, Mockett, & Doherty, 2001; Mat, Ng, & Tan, 2017; Takacs, Carpenter, Garland, & Hunt, 2015), as well as reduced ability to absorb the forces associated with a fall in studies involved induced leans (Levinger, Nagano, et al., 2016b). This may be as a result of an argued loss of proprioception experienced in OA (Sharma & Pai, 1997). The development of a link between proprioception and falls in older adults with knee OA has, to date, been limited. However, much discussion has been had in relation to joint positioning with age (Barrett, Cobb, & Bentley, 1991; Hassan et al., 2001; Knoop et al., 2011) with the prevailing view that proprioception is not as accurate in older adults as seen in younger. Whether joint conditions such as OA exacerbates this is unclear with some arguing in favour of reduced proprioception in this population (Barrett et al., 1991; Hassan et al., 2001; Knoop et al., 2011) and others arguing against (Bennell et al., 2003). While balance is clearly an issue of concern amongst older adults with knee OA (Hassan et al., 2001) it is not yet clear if joint proprioception is in response to joint disease, results in it (Barrett et al., 1991), or has no association at all (Bennell et al., 2003; Knoop et al., 2011). The anatomy of the knee, particularly the tibiofemoral joint (Figure 2.2), may also be a contributing factor for the lack of stability in those with OA. The demand for stability and control during a range of load-bearing conditions, and the allowance of motion from the bony architecture (Goldblatt & Richmond, 2003) might perhaps explain the increased falls risk in OA where there is poor proprioception in hand with a highly mobile joint structure.

2.5.3 Impaired strength in knee osteoarthritis and risk of falls

The relationship between strength and falls in OA is, at best, a highly varied discussion. While higher strength in both the hamstring and quadriceps femoris groups has shown to decrease falls risk in OA (de Zwart et al., 2015), when pain is considered within the analysis it appears to reduce statistical association between strength and falls (de Zwart et al., 2015). This may be a result of the influence of pain, or because strength appears to vary widely across the range of OA where those with lower function also have lower contractibility (Berger, McKenzie, Chess, Goela, & Doherty, 2012). Adding further complexity to this issue is the influence on strength and falls from Sarcopenia leading to a view that it may not be OA that limits strength as opposed to it being a normal part of the ageing process. Strength may play an important role in relation to falls risk in older adults with knee OA but the presence of pain may be a confounding variable. This may be as a result of how strength and muscle function interacts with falls. In particular the function of the knee flexors and extensors acting as dynamic ligaments about the knee joint (Manlapaz et al., 2019) and the question as to whether OA impacts on joint positioning directly, or indirectly via reduced strength mechanism, and then to falls.

2.5.4 Pain, its relationship with knee osteoarthritis and risk of falls

Pain is defined as both a sensory and emotional experience that is both unpleasant, and associated with tissue damage (Merskey & Bogduk, 1994). Pain perception can be triggered by the injury and/or disease (nociceptive) but also by lesion to the central nervous system (neuropathic). Furthermore, suffering may or may not be caused by pain, but may be also because of negative response to feelings around this, including fear and loss. Therefore, pain behaviour is the response of the individual to both perception and suffering (Loeser & Melzack, 1999). Gate control theory (Melzack & Wall, 1965) discusses the mechanics of how the central nervous system controls response to acute pain stimulus, particularly the efferent response. The theory states, simply, that there is a neurological gate located in the spinal cord which can either block a pain signal or allow the signal to proceed to the brain. This

is achieved via the dimension of the fibres carrying the pain signal. Larger fibres excite inhibitory neurons which then diminishes signals, while small fibres tend to let them proceed via less inhibitory action. Where there is ready transfer of signals, more pain is felt. While this seminal work highlights some key components of the stimulus-response relationship, it does not address the long-term influence of pain on the individual arising from injury sites such as joints.

Pain, particularly of the joints, is a common concern for older adults (Croft, Rigby, Boswell, Schollum, & Silman, 1993), with approximately one in eight of this population reporting knee pain (Lawrence et al., 1998). Those with knee OA commonly report one of two types of joint pain, intermittent severe, or persistent aching (Hawker et al., 2008). The persistent pain does not impact on quality of life to the same extent as the intermittent due to the impact of the latter on mood state, confidence, and avoidance of pain triggering activities including both social and recreational pursuits (Hawker et al., 2008). In community-dwelling older adults, chronic pain and depression are independently associated with falls risk (Eggermont, Penninx, Jones, & Leveille, 2012), possibly via impact to executive function (and associated distraction caused by pain) or sleep patterns (and the associated fatigue leading to non-ideal movement). In knee OA, however, it appears that acute pain presents more of a challenge to the individual's quality of life than does chronic. A difficulty in understanding pain and falls risk in OA is that, while it is a core symptom of knee OA (Linaker, Walker-Bone, Palmer, & Cooper, 1999) it's correlation with progression of the disease is poor (Muraki et al., 2009). What is known, however, is that older adults with chronic knee pain have lower levels of physical activity (Stubbs et al., 2013), are less able to avoid obstacles during gait (Pandya, Piotrowski, Pottenger, & Draganich, 2007), and appear less confident in ability to avoid a fall (Stubbs, West, Patchay, & Schofield, 2014)

Pain is a well reported, and important, risk factor for falls with approximately half of older adults with pain reporting one or more falls in the previous year when compared to those without pain (Stubbs, Binnekade, et al., 2014a). There exists a linear relationship between pain and stability in obstacle crossing, for example, where around one third of the reduction in successful avoidance is connected to feeling pain (Pandya et al., 2005). Given that pain research centres on both perception and behaviours, it is important to address the question as to whether

these responses arise from physical pain (nociceptive or neuropathic) or from suffering because of the physical pain. In research involving falls from induced leans in older adults with knee OA, there were higher pain scores noted in those taking multiple steps to recover balance (Levinger, Downie, et al., 2016). The exact nature of this finding, however, is unclear with noted poor performance in locomotor function but not necessarily in stability (Levinger, Downie, et al., 2016). This may be because of pain being a poor indication of progress of knee OA (Salaffi, Cavalieri, Nolli, & Ferraccioli, 1991), or because the attentional demand of pain (Eccleston & Crombez, 1999) resulting in a cognitive challenge to the sufferer. This cognitive challenge may well serve to limit function. As an example, experimentally induced pain interferes with postural control, particularly so with a more difficult cognitive challenge present (Suda et al., 2019).

While the findings in Levinger et al (2016) were not significant they could suggest that further studies addressing pain categorisation may provide clearer insight. With more in-depth analysis of pain, including type, perceptions to pain, level of suffering from pain and any behavioural changes arising from the presence of pain, more clarity with respect to the influence of pain on falling might be afforded.

2.5.5 Executive function, its relationship with knee osteoarthritis and risk of falls

Executive function is a grouping of higher order cognitive processes, including task switching and planning (Gilbert & Burgess, 2008), which control behaviours in a wide array of conditions such as when moving. As we age, executive function appears to be impacted through the apparent changes noted in the frontal lobes (Lorenz-Reuter, 2000), which happen to impact on reduced processing speed, executive function and memory function (Gunning-Dixon & Raz, 2000). Executive function is generally thought to continue in healthy ageing, but with decline in areas such as attention (Yogev-Seligmann, Hausdorff, & Giladi, 2008). In the absence of dementia, impairment of cognitive function has been associated with increased falls risk (Liu-Ambrose, Ashe, Graf, Beattie, & Khan, 2008; Muir, Gopaul, & Montero Odasso, 2012). Deficiency of gait is also consistently associated with falls risk in older adults with reduced cognitive function (Ganz, Bao, Shekelle, & Rubenstein, 2007),

presumably arising from the impact this has on movement regulation (Hausdorff & Yogev, 2006). In older adults with mild cognitive impairment, gait speed decreases at a higher level where there is a secondary cognitive challenge when compared with healthy older adults (Muir, Speechley, et al., 2012). While there is noted gait speed decrement with age, there is a further impost where cognition is challenged, creating a possible link between decline in this domain, and movement control.

The connection between age-related cognitive performance and physical function has, traditionally, been viewed as two distinct realms (Mirelman et al., 2012). While falls risk increases with conditions such as dementia, any causal link between the two domains in the absence of such extreme executive function decline has not clearly been elucidated (Mirelman et al., 2012). Via the use of an executive function index, however, as a combined measure of response inhibition, reaction time and errors in judgement, each incremental increase is associated with a reduction in falls risk (Mirelman et al., 2012). Such results have fuelled a shift away from the traditional binary view of dementia and falls risk, to a more broad belief that there is a spectrum of cognitive function that may correlate with, and be a predictor of, falls risk (Mirelman et al., 2012).

In older adults with knee OA, there are established links between poor executive function and slower gait speed (Morone, Abebe, Morrow, & Weiner, 2014), and while there are known links between falls and slow gait there has not been, as yet, any causal link between the biomechanics of stability and executive function in this group. Perhaps the reason for such debate around the link between executive function and falls is through the appropriateness of testing those with severe deficits in this domain. While the exclusion of those with severe cognitive degradation is necessary for the ability to test other areas of function (Tinetti et al., 1988), this may serve to both underestimate the potential for a cognitive impost on balance, as well as overestimate any influence. Put simply, is poor balance a result of a decline of executive function or does cognitive decline result in poor balance? Without testing, it is neither possible to confirm, nor deny, the influence of higher levels of cognitive impairment on balance and locomotor function.

2.6 Stability in knee osteoarthritis

As highlight earlier in this chapter (2.3.1 Defining balance and stability) current research discussion around falls uses terms such as ‘balance recovery‘ (Aftab et al., 2012, 2016; Carty, Cronin, et al., 2012a; Carty et al., 2011; Do et al., 1982; Downie, 2014; Graham et al., 2015; Hsiao & Robinovitch, 1999; Levinger, Nagano, et al., 2016a; Maki, Edmondstone, et al., 2001; Maki & McIlroy, 2006) to describe the action that avoids a fall. The common theme in these works is the identification of stepping response following perturbation, either single or multiple. Using the definition of stability in this thesis, if the subjects took only one step, they were stable, or if they took multiple steps, they were unstable. Such a response is associated with increased falls risk (Carty, Barrett, et al., 2012; Carty et al., 2011; Maki & McIlroy, 1997, 1998). In these studies, involving otherwise healthy older adults stability was demonstrated via the taking of a single, high velocity step with higher activation of quadriceps femoris muscles, quicker movement, and a more upright upper body. Such actions serve to maintain the centre of mass position within the base of support.

Research into stability in older adults with knee OA has, to date, been limited, with studies showing shorter and slower steps following perturbation, though not significantly (Downie, 2014; Levinger, Downie, et al., 2016). These studies did also show some significant difference in knee extensor strength in this population that, in hand with the large effect size associated with the spatio-temporal variables, may have suggested that the activity of the knee OA group was similar to that of otherwise healthy older fallers. While lower limb activity suggests poor stability in this group, neither Downie nor Levinger et al investigated the influence of the upper body on stability following perturbation. Systematic reviews support the broad discussion of poor balance, muscle function, comorbidities, and pain in knee OA, however the lack of strength in the evidence diminishes these findings (Manlapaz et al., 2019). Despite the known risk of falls in older adults with knee OA, the exact contributors to this risk are not yet clear (Levinger, Nagano, et al., 2016b). While there is a possible connection between dynamic posture and falls risk (Levinger, Nagano, et al., 2016a), exactly what type of posture might be most stable during a fall in older adults with knee OA is unclear.

2.7 Summary of past research and study aims

Falls in older adults are a major public health concern globally and, furthermore, are a major personal challenge for the individual with a history of, or is at risk of, falls. The lower limb, especially the knee, and upper body appear to have a great influence on poor balance, as does the motion of the trunk. Where the centre of mass from these segments fall inside the base of support, the individual will avoid a fall. When they exceed the base of support, it increases falls risk. Distraction, obstacle clearance, pain and executive function all appear to have some level of influence on stability performance, but it is not clear to what degree in people with knee OA. Thus, the overall aim of the studies presented in this thesis was to identify the differences in the biomechanical response to inducted falls in people with knee OA compared to asymptomatic older people and to explore the link between pain, executive function and balance response and future falls.

Chapter 3 – General Methodology

This chapter includes the common methods used across all study chapters included in this thesis, as well as methodology specific to each chapter. It also includes, general research design, including inclusion criteria and recruitment. Data collection description includes 3D motion capture, and an outline of the biomechanical collection procedures and broad description of the approach to data analysis applicable across all study chapters of this work.

3.1 Ethics

The experimental protocol used in this thesis was approved by the Human Research Ethics Committee, Victoria University (HRE16-065) in accordance with the standards of the Declaration of Helsinki.

3.2 Research design

This thesis employed cross sectional study design comparing two groups (Chapter 4), a correlational study in Chapter 5, and a prospective cohort study design with 12 months follow up (Chapter 6). Older people with knee OA (knee OA group) and asymptomatic controls (control group) were assessed to investigate biomechanical responses to induced falls across three conditions (no additional challenge, cognitive dual-task challenge, and physical dual-task challenge). Individual study chapters are as detailed below:

- Chapter 4: Interactions and differences between groups (control and knee OA) and trial conditions (no additional challenge, cognitive dual-task challenge, and physical dual-task challenge,
- Chapter 5: The effect of pain and executive function on biomechanical response to falls from induced leans in older adults with knee OA, and

- Chapter 6: A prospective cohort study design with 12 months follow up to predict falls in sub-group of older adults with knee OA

3.3.1 Inclusion criteria

Inclusion criteria for all participants in this thesis included:

I. Aged 60 years and over,
II. Self-ambulatory,
III. Community dwelling (including living at home and independent living within a retirement village but not including living in a care facility),
IV. No neurological condition (such as stroke, multiple sclerosis, Alzheimer disease, Polio, or Parkinsonism), and
V. For Chapter 9 only, with no cognitive decline as assessed by the St Louis University Mental Status exam (score of < 20 (or 21 < for participants with high school education) as detailed in 3.6.1 below)

Inclusion criteria for the OA group included:

I. Diagnosis of knee OA was based on the guidelines of the National Institute for Health and Care Excellence guideline CG177 (NICE, 2014). The NICE guidelines includes three categories that people have to meet to be diagnosed as having OA:
    a. Aged 45 or over,
    b. Have activity related joint pain, and
    c. Either no morning joint stiffness, or joint stiffness less than 30 minutes.

    For inclusion in this thesis, participants needed to be at least 60 years old.

3.3.2 Recruitment

Participants were recruited from the Victoria University community, as well as through advertisements in western suburbs newspapers, seniors' related print and radio media, seniors' associations, social media, flyer distribution to western suburbs medical centres and presentation to senior groups.

3.4 Apparatus

3.4.1 Motion capture

Three-dimensional motion capture, and calculation, of kinematic variables was conducted via a Vicon system (VICON, Oxford Metrics). For this research, the capture rate was set to 1000Hz.

3.4.1.2 Motion Capture Cameras

Twelve Vicon MX-T 40s cameras (VICON, Oxford Metrics) fitted to tripod mounts were placed to create a capture zone approximately 10m long and 8m wide. In order to ensure marker visibility by the most cameras, half (cameras 1, 2, 3, 7, 8, and 9) were placed laterally to the capture zone (being the location of the force plates, section 3.2.2) with three (cameras 4, 5 and 6) placed posteriorly to the participant, and three (10, 11 and 12) placed anteriorly (Figure 3.1).

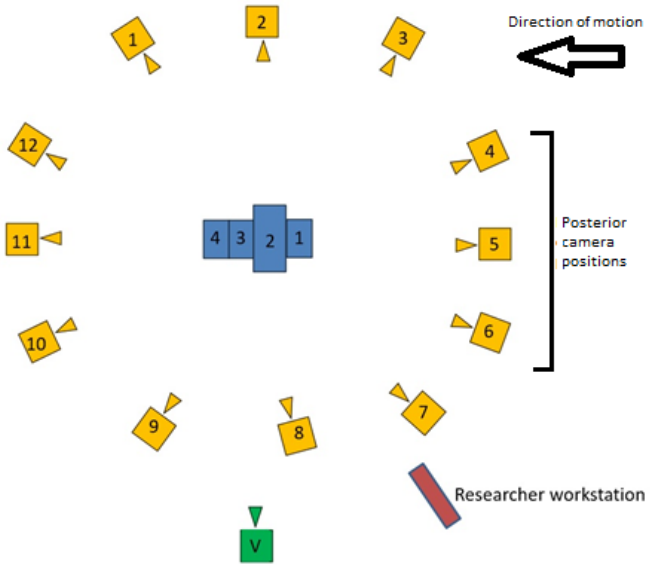


Figure 3.1 - Lab setup, AMTI force plates (1-4) in blue, Vicon cameras (1-12) in yellow with numbers 4,5 and 6 posterior to the participant. Researcher workstation location to the bottom right, and video camera in green. At commencement of the trial, participant

3.4.1.3 Calibration

Prior to commencement of falls recovery trials, the Vicon system was calibrated as per the manufacturer's instructions. Conducting system calibration corrects distortion of the camera lens field of view, particularly focal length image distortion and the erroneous digitisation of other Vicon cameras (Vicon, 2006). Performing system calibration ensures that, in the capture zone, there are no objects which may create difficulty in either capture, or processing of data. This may include items which may reflect the infrared light used in this system, such as other Vicon cameras.

3.4.2 Forces

3.4.2.1 Force plates

Four AMTI (Watertown, MA, USA) force plates (one model BP600900TT, and three model BP508600TT) were used in this research for identification of foot contact. Plates were designated as number 2 for the BP600900TT and numbers 1, 3 and 4 for the BP508600TT (Figure 3.1). Dimensions for the BP600900TT were 900mm x 600mm x 102mm, and the BP508600TT 508mm x 600mm x 82.5mm. The latter plates were custom made for Victoria University. Force plate capture rate was set to 1000Hz and synchronised with the Vicon system. Force plates were used for collection of force related data, and identification of events.

3.4.2.2 Force measurement, horizontal and vertical

Two force transducers (Australian Weighing Equipment BRN: A3302203:LT:4) were used to measure both horizontal and vertical forces generated by participants during falls recovery trials. The overhead transducer was attached to the overhead frame (Figure 3.2) and then to the participant's harness (section 3.5.3.2), with the horizontal attached to the rear frame (Figure 3.3) and to the fitted belt (section 3.5.3.3). The force transducers were synchronised with the Vicon system.

3.4.3 Participant safety and Tether Release equipment

3.4.3.1 Frames

Two frames (Figures 3.2 and 3.3 below) were fabricated by Victoria University Biomechanics laboratory technical staff in order to provide safety for participants, as well as provide anchor points for force transducers (section 3.5.2.2) and to provide the induced lean for falls recovery trials. In the case of the overhead frame (Figure 10), the harness worn by participants (section 3.5.3.2) was connected via D-ring and rope to a crossbar for safety. In the case of the rear frame (Figure 3.3), the belt worn by participants (section 3.5.3.3) was connected via an electromagnet to the frame in order to produce the induced lean at the start of trials (section 3.5.3.4).

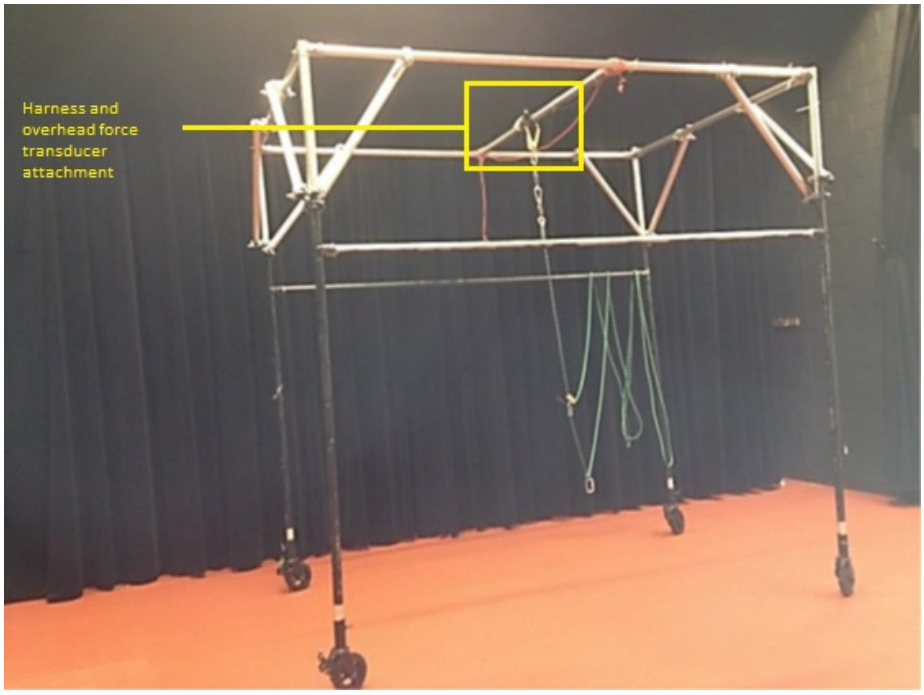


Figure 3.2 - Overhead frame, note the position of the harness attachment on the centre crossbar (rope attachment point) where the overhead force transducer is located.

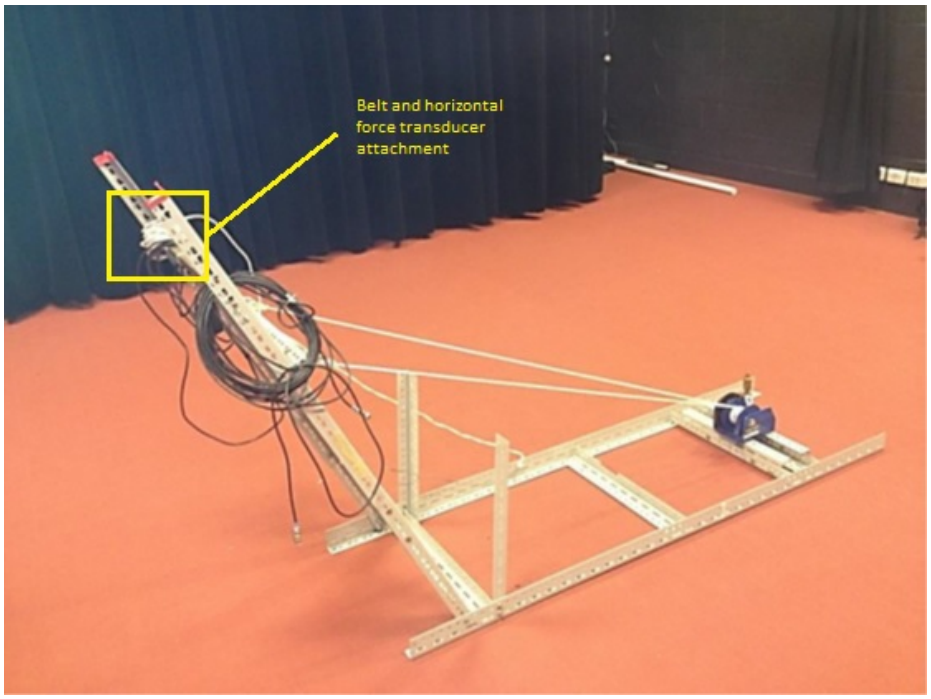


Figure 3.3 - Rear frame, note the position of the belt attachment on the horizontal crossbar where the rear force transducer is located.

3.4.3.2 Harness

To ensure participant safety during falls recovery trials a protection harness (Miller MA08 Duraflex 2 Point Fall Arrest Harness) was worn by subjects (Figure 3.4). The harness was adjusted to meet the dimensions of legs, chest, and shoulder of each participant.

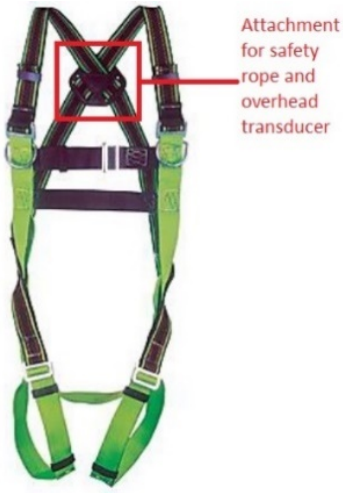


Figure 3.4 - Miller MA08 Fall Arrest Harness, anterior view. Note the adjustable upper back plate which has, on the posterior surface, a D ring for attachment of both the safety rope and tether for the overhead force transducer.

3.4.3.3 Belt

To create the induced lean position for the start of the falls recovery trials, a belt was fabricated by Victoria University Biomechanics laboratory technical staff (Figure 3.5). The belt was fitted with a metal plate to which the electromagnet was attached. The belt was placed at the height of the Umbilicus. To avoid participant bending at the height of the belt, participants were assisted into the commencing position (Figure 3.6) to avoid bending. Participants were also encouraged to allow themselves to place their full bodyweight in the harness. Once this was achieved, participants were placed into the induced lean to commence the trials.

Figure 3.5 - Fabricated belt, note the fitted metal place to which the electromagnet was attached.

3.4.3.4 Electromagnet

A single, 12v, R-2025-12 electromagnet (Magnatech Corporation, Novi MI, USA) was attached to the rear frame (Figure 3.3). Once fitted with the harness and belt, participants were then connected to the electromagnet and were then placed in the induced lean with feet flat on the floor to start the trial (Figure 3.6). To commence the trial, the power was remotely switched off by the researcher as part of the Tether Release Method (Section 3.5.1.3.4).

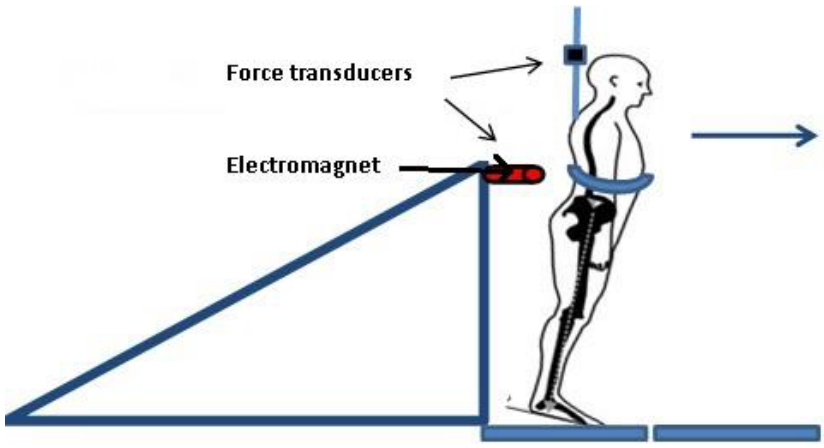


Figure 3.6 - Induced lean and position of electromagnet

3.5 Procedure

Testing was carried out in the Biomechanics laboratory, Victoria University Institute for Health and Sport, Footscray Park campus.

People in the community, who were interested in taking part in the study, were screened, using inclusion criteria over the phone. (Appendix 1). Eligible participants were then sent an information pack (Appendices 2 and 3) and invited to attend the Biomechanics laboratory at Victoria University, Footscray Park campus. On arrival, all participants completed a consent form for the studies (Appendix 3). For participants meeting all inclusion criteria (including SLUMS testing for Chapter 5 only, see Appendix 4), a comprehensive medical history (Appendix 5) and medication record (Appendix 5) was taken. After this collection, for subjects chosen for Chapter 5, executive function assessments were conducted (Appendices 6, 7, and 8). Following this all participants were prepared for the biomechanical falls recovery trials with reflective marker placement, fitting of body harness and belt (all study chapters). After biomechanical data collection was complete, participants chosen for Chapter 5 analysis completed pain assessments (Appendices 9, 10, 11, 12 and 13), following which falls, quality of life and physical activity data were collected. Finally, functional assessment was completed.

3.5.1 General procedure

3.5.1.1 Phone screen

The first section of the phone screen (Appendix 1) included general inclusion questions around age group, living arrangements (do they live in care or independently), whether they have difficulty in walking activity, a condition of the lower limb, and have been diagnosed with a neurological condition.

The next section included NICE clinical diagnosis criteria (NICE, 2014) covering presence of pain, and which leg is dominant (if the pain is bilateral) or affected (if the pain is unilateral). Based on this leg; how many weeks/years have they had pain,

how bad the pain was at the time of the call (0-10) and the week proceeding on average (0-10), when they felt the pain most often (morning, midday, night), where they felt the pain (in bed, sitting, active). And, if active, is the pain more when walking (flat or uneven surface), or on stairs (ascending or descending). Lastly, for the dominant or affected limb, how does the pain affect the subject. These limb related questions were then asked for non-dominant limb, where both limbs affected.

The final two sections of the phone screen reference general medical history, including conditions not already discussed and history of surgeries, and falls in the past 12 months, whether the subject is concerned about falling and if they take action to avoid falls.

3.5.1.2 Medical history collection and medication recording

Following the confirmation of inclusion arising from the SLUMS exam, the researcher investigated fully the medical history, and any medical conditions which may have precluded further participation (Appendix 5).

The medical history taken at this point is as per the phone screen covering age, living arrangements, presence of musculoskeletal condition of the lower limb and absence of neurological disorder. This is followed by NICE (NICE, 2014) diagnoses detail of the dominant or impaired limb (where there is, respectively, bilateral or unilateral OA involvement) and questions around length of time for pain, as well as level of pain and where the pain is most prevalent.

Medication recording includes all medications taken, for what purpose, at what dose and whether it is prescribed. Finally, this section also noted pain medications taken in the 24-48 hours prior to assessment as well as what was taken.

3.5.1.3 Biomechanical data collection

Prior to collection of biomechanical data, anthropometric data were collected including age, body mass and height. Furthermore, the following measures were also collected for Vicon dimensions; upper body (shoulder offset, and elbow, wrist, and hand width) and lower body (inter ASIS distance, leg length and pelvic, knee and ankle width) (Table 3.1). These dimensions were entered into the Vicon system to create the individual participant's model. The trunk segment was defined using Torso markers (Figures 3.7 and 3.8) including both anterior (Clavicle and Sternum) and posterior (7^{th} Cervical, 10^{th} Thoracic and right back). As participants were shod during trials, they were weighed with shoes on to include the mass of the items in the overall subject's mass.

Table 3.1 - Anthropometric measures for Vicon (Vicon, 2006)

Measurement	Unit	Notes
Mass	Kg	Shod, via digital scales
Height	Cm	Shod, via height measuring device
Shoulder offset	Cm	Vertical distance from the Acromial marker and the centre of the shoulder joint, bilateral
Elbow width	Cm	Width of elbow joint in flexion, between the Humeral Epicondyles, bilateral
Wrist width	Cm	Width of wrist joint, at the Styloid Processes, bilateral
Hand thickness	Cm	Width of the hand between the Dorsum and Palmar surfaces, bilateral
Inter ASIS distance	Cm	Distance between left and right Anterior Superior Illiac Spines
Leg length	Cm	Length from ASIS to Lateral Malleolus, bilateral
Knee width	Cm	Width of knee joint, Medio-laterally between the Femoral Epicondyles, standing, bilateral
Ankle width	Cm	Width of ankle joint, Medio-laterally, standing, bilateral
ASIS to Greater Trochanter distance	Cm	Vertical distance between the Anterior Superior Illiac Spines to Greater Trochanter, bilateral

3.5.1.3.1 Marker placement

Before commencing trials, 48 14mm diameter reflective markers were attached to the participant's head, torso and upper limbs, pelvis and lower limbs on landmarks as specified in the Oxford Metrics Plug In Gait model (Oxford Metrics Group, Oxford, England) and shown in Fig.3.7 and 3.8. In order to provide better tracking of markers during the induced lean, and where participants' adipose tissue occluded anterior superior illiac spine markers, two extra markers were placed on the most lateral point of the superior illiac spine.

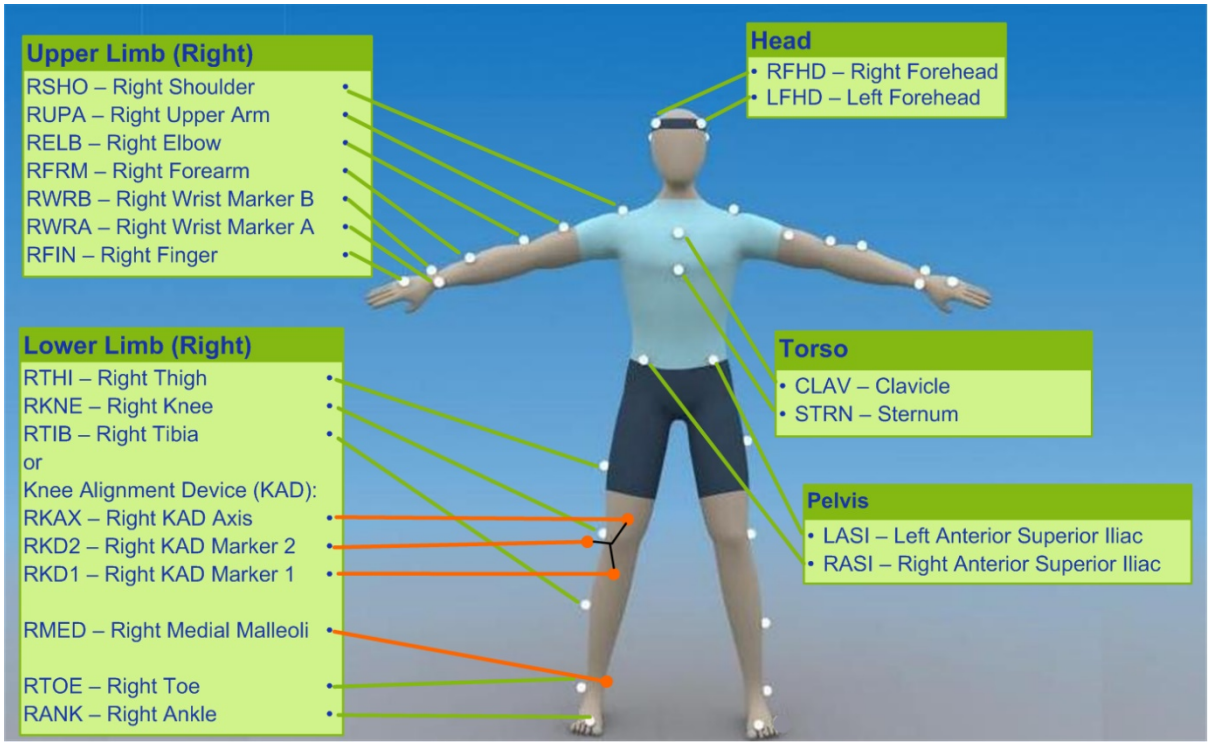


Figure 3.7 - Vicon Plug In Gait bony landmark locations for placement of reflective markers (anterior view)

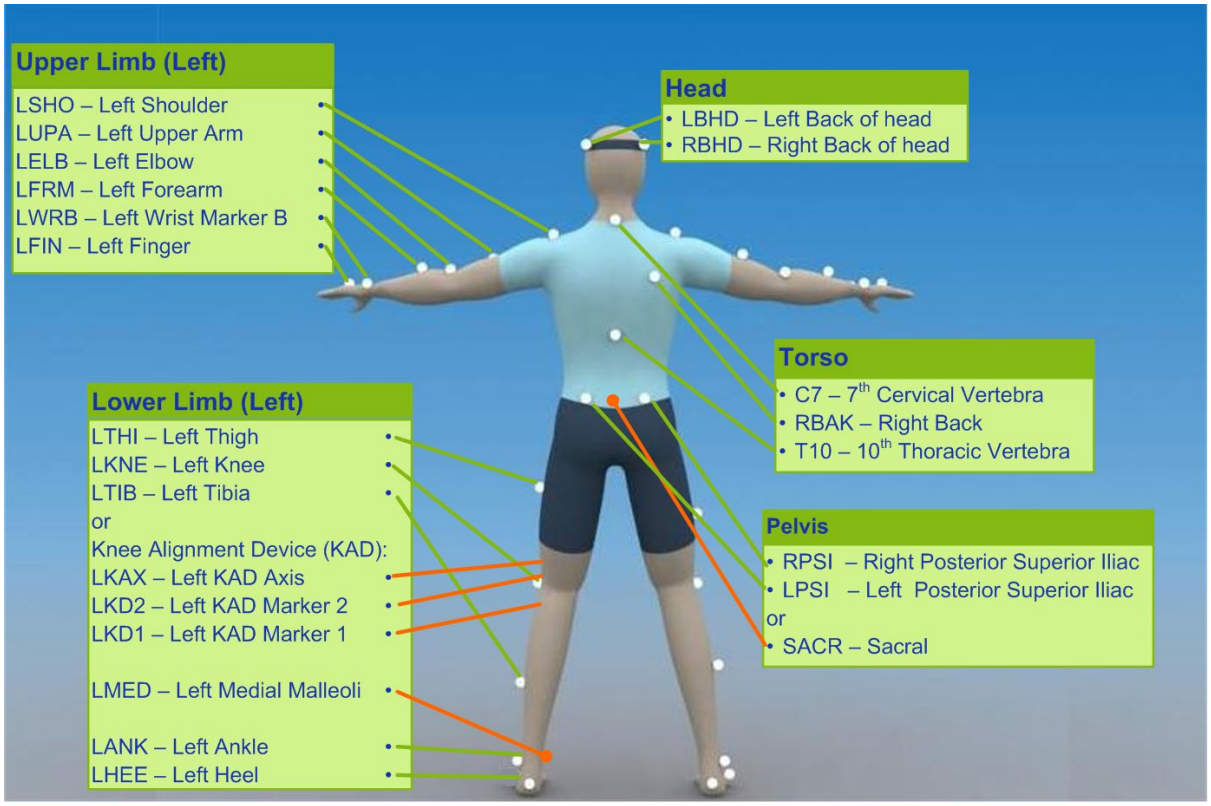


Figure 3.8 - Vicon Plug In Gait bony landmark locations for placement of reflective markers (posterior view)

3.5.1.3.2 Static trials

After participants were prepared for biomechanical data collection, and before the falls recovery trials commenced, they were instructed to stand on force plate number 1 facing plate number 4 (Figure 3.1). Once in this position, Vicon Knee Alignment Devices (KADs) were placed on the participants for the motion capture system to determine the alignment of the knee during study trials. Two static trials were taken to ensure that the Vicon system was able to digitise all markers. Prior to commencing the falls recovery trials, the KAD's (markers LKAX, LKD2, LKD1 and RKAX, RKD2 and RKD1 in Figures 3.7 and 3.8) were removed and replaced with 14mm reflective markers at the Lateral Femoral Epicondyles. The medial ankle markers (LMED and RMED in Figures 3.7 and 3.8) were also removed.

3.5.1.3.3 Stability trials

On completion of static trials, participants were attached to the rear frame via the electromagnet and were briefed on the safety aspects of the trials as well as the expectation of the participant. The instruction for the subject was, on release of the electromagnetic tether and the initiation of the fall, they were to attempt recovery by the taking of a single step. To familiarise the participant with the protocol, two practice attempts were conducted at a lean angle less than what would be experienced during trials with the researcher standing with the subject for their comfort. Following these practice attempts, each participant then completed nine study trials under three conditions (three trials for each condition) chosen randomly from the following,

I. No additional challenge: fall recovery task with neither cognitive, nor obstacle crossing task
II. Cognitive dual-task challenge: fall recovery while undertaking a cognitive task (counting backwards from 100 by seven)
III. Physical dual-task challenge: fall recovery while undertaking an obstacle task (stepping over an obstacle)

3.5.1.3.4 The Tether Release Method

The protocol used in this project, the Tether Release Method (Figure 3.9), is based on previous works (Barrett et al., 2012; Carty, Cronin, et al., 2012b; Carty et al., 2011; Do et al., 1982; Downie, 2014; Levinger, Begg, et al., 2017a; Levinger, Downie, et al., 2016; Levinger, Nagano, et al., 2016a; Levinger, Nagano, et al., 2016b; Nagano et al., 2015b). Participants stood with feet shoulder width apart, and flat on the ground. Following attachment to a waist height tether, subjects were placed into an induced forward lean with their bodyweight resting on a fitted harness. Once 20% of the participants body weight force was registered on the vertical force transducer the trial was commenced as described in the above works. The necessitation for recording 20% of body weight on the force transducer has been shown previously as a point of difference between subjects taking single or multiple

steps in falls recovery (Karamanidis et al., 2008; Thelen, Wojcik, Schultz, Ashton-Miller, & Alexander, 1997). The researcher disconnected power to the electromagnet at a random time interval and with no warning thus inducing a fall. The responses of the participants during the resulting fall were recorded by the study apparatus and were classified as either single or multi-stepper during analysis as per the aforementioned works. The employment of a multi-stepper response is predictive of falls risk (Carty et al., 2011; Maki & McIlroy, 2006).

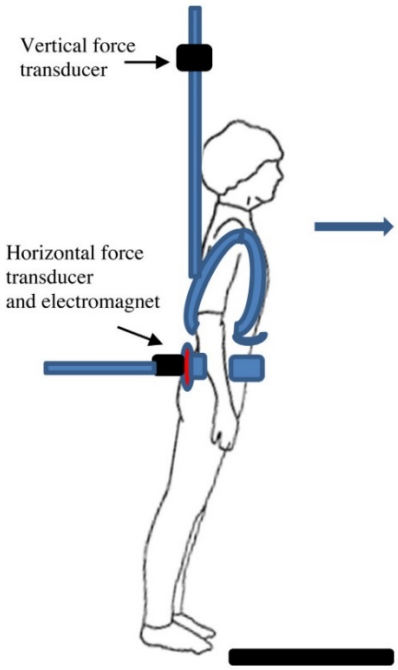


Figure 3.9 – The Tether-Release method start position (adapted from Levinger et al. 2016).

3.5.1.3.4.1 Cognitive dual-task challenge trials

Where trials involved cognitive dual-tasks, participants were instructed to count aloud backwards from 100 by a factor of seven. At a random point during this testing the power to the electromagnet was removed.

3.5.1.3.4.2 Physical dual-task challenge trials

Where trials involved physical dual-task challenges, a foam obstacle (Figure 3.10) was used that was 1cm wide and 4cm high. The height of the obstacle was chosen to represent typical household obstacle height, and the placement was described previous as the typical location of minimum toe clearance (Patla & Rietdyk, 1993).

Figure 3.10 - Foam obstacle (1cm x 4cm) used during obstacle clearance trials with fitted reflective marker for digitisation in Vicon

3.5.1.3.5 Biomechanical data processing

Motion capture data was processed in Visual 3D (v6. C-Motion, Germantown, MD, USA). Initial processing included all trials, with the first of each participant's trials, in each condition, included in analysis. A pipeline was created in Visual 3D to extract the desired variables.

3.5.1.3.6 Parameters for investigation

The following parameters were investigated at foot placement of the first step of falls recovery:

I. COM_{vel} – velocity of the COM in the anterior direction,
II. MOS – distance of the COM from the boundary of the BOS in the anterior direction (Figure 3.10),
III. ART – time taken (s) for the COM to reach the boundary of the BOS (Nagano, Begg, & Sparrow, 2013)
IV. RHP – position of the front of head marker, with relation to the marker on the toe of the recovery limb (Figure 3.11).
V. $STEP_{length}$ – length taken in first recovery step (Figure 3.12)
VI. $STEP_{time}$ – time taken in for first recovery step
VII. $STEP_{vel}$ – $STEP_{length}/STEP_{time}$
VIII. $ANKLE_{angle}$ – measure of the angle between the foot and shank segments, at foot contact (Figure 3.13)
IX. $ANKLE_{moment}$ – moment about the ankle joint.
X. $ANKLE_{power}$– Ankle joint power
XI. $KNEE_{angle}$ – angle between the shank and thigh segments, at foot contact (Figure 3.13)
XII. $KNEE_{moment}$– moment about the knee joint
XIII. $KNEE_{power}$– Knee joint power
XIV. HIP_{ang} –angle of the hip between the trunk segment and thigh, (Figure 3.13),
XV. $HIP_{ang.vel}$ –$\Delta HIP_{ang}/STEP_{time}$
XVI. $TRUNK_{ang}$ – the angle of the trunk with respect to the vertical axis (Figure 3.13), and
XVII. $TRUNK_{ang.vel}$ - $\Delta TRUNK_{ang}/STEP_{time}$

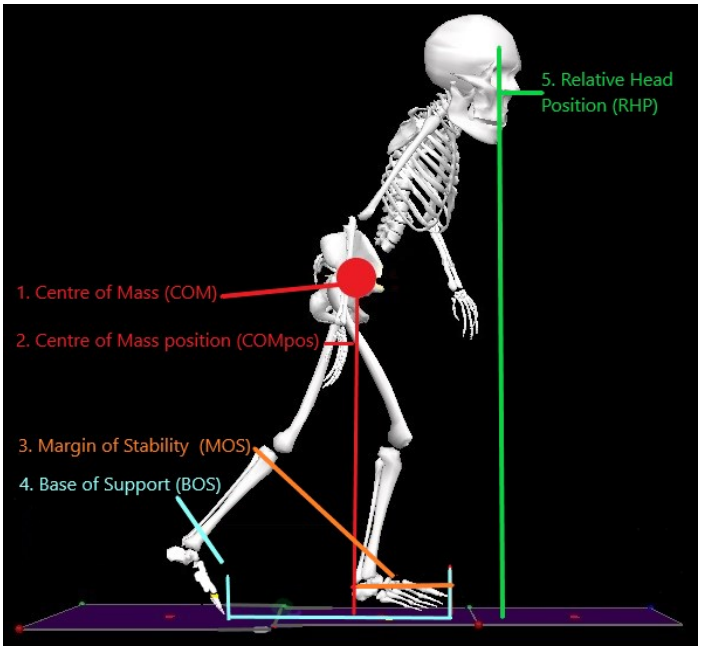


Figure 3.11 - 1. Centre of Mass (red) located about the Pelvis, 2. COMpos (red) location of COM with respect to recovery foot, 3. MOS (orange) distance of the COM from the boundary of BOS, 4. BOS (light blue) area of ground contact, 5. RHP (green) position of the head relative to the recovery foot

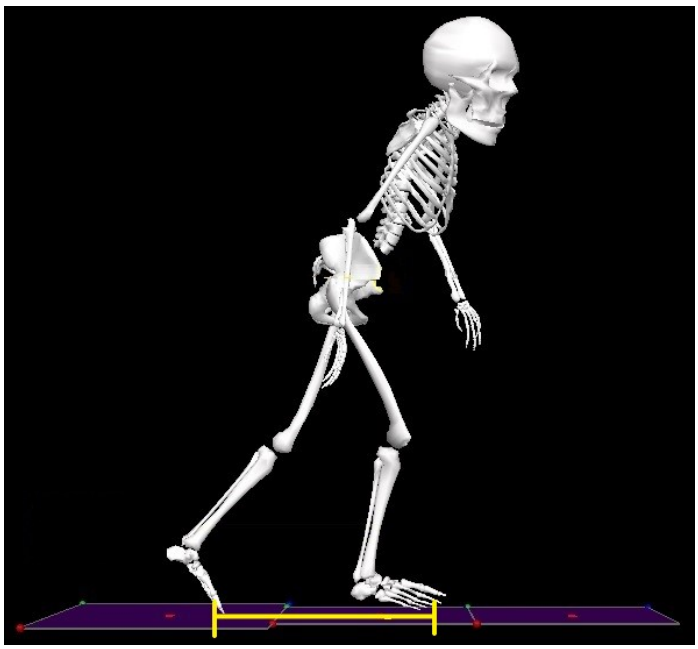


Figure 3.12 - Step Length (from start position to toe contact of first step)

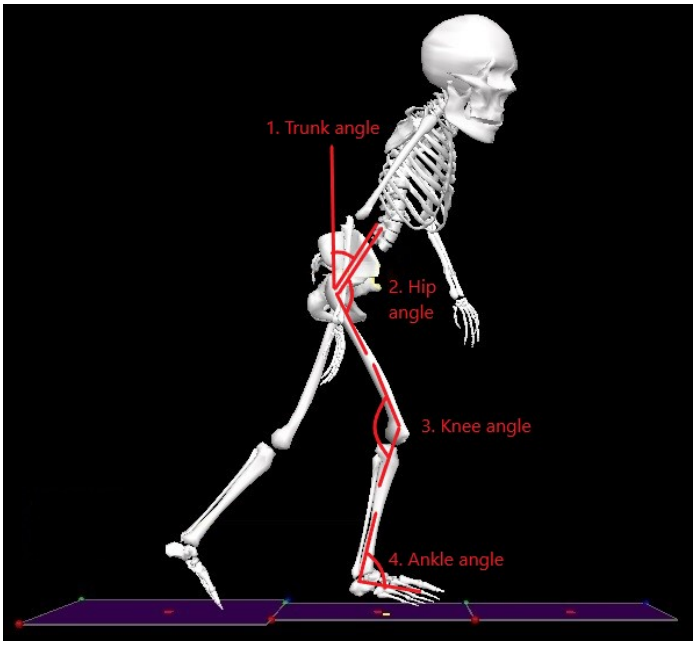


Figure 3.13 - Joint kinematics. 1. Trunk angle relative to the vertical axis, 2. Hip angle relative to the trunk. 3. Knee angle relative to the thigh and 4. Ankle angle relative to the shank

3.5.1.3.7 Biomechanical events and spatio-temporal parameter classification

Foot contact was defined as the first observed contact of the recovery foot with the ground by the appearance of a vector resulting from force plate contact. Where the step was not on a force plate, foot contact was defined as ankle plantar flexion over a period of three consecutive frames (0.03s) to confirm a pattern of movement (Nagano et al., 2015b). Relative head position was calculated as the difference between the related anterior head marker and the toe marker on the recovery foot. Where the recovery was made with the right limb the right head marker was used and the left head marker was used where left foot recovery occurred. Centre of mass position was tracked as part of the plug-in-gait model, and from this velocity of centre of mass was derived. Both MOS and ART were calculated as previously described (Nagano, Levinger, Downie, Hayes, & Begg, 2015a).

3.5.1.3.8 Exception handling

Markers were placed as per the Plug-In Gait model (Figures 3.7 and 3.8) but these markers at times can be occluded from motion capture systems (Levine, Richards, & Whittle, 2012) necessitating amendment. To achieve this, two approaches were taken,

I. Extra markers were attached, laterally on the pelvis (superior illiac spine), to aid in tracking of the segment where anterior superior illiac spine markers were not visible.
II. The trajectory of missing markers was interpolated where the gap was up to 10 frames

3.5.1.4 Western Ontario and McMaster Osteoarthritis Index

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (Bellamy, 2016) (Appendix 11) is a group of questionnaires used by clinicians to assess osteoarthritic pain, stiffness and physical function. In this assessment, participants are asked a series of questions on pain, stiffness, and function. With respect to pain, is it when walking, descending, or ascending stairs, while in bed, sitting or lying down and when standing. With respect to stiffness, questions relate to when this occurs, either early or late in the day. Finally, with respect to function including going up and down stairs, when standing up and while standing, while bending and walking on a flat surface. This section finishes with difficulty alighting a bus, while shopping, dressing, and undressing, getting in or out of the bathtub, off the toilet and when doing household work.

As the tool was administered at different times, both the VAS (VA3) and LIKERT (LK3.1) were used. The VAS version uses a 100mm visual analogue scale where the subject places a mark at the appropriate point of the scale that correlates with their response, and the clinician measures this to determine a score out of 100. For the LIKERT version, subjects tick a box with their choice of response; none, mild, moderate, severe, or extreme. This provides a score ranging from 0 to 4 for each question, with 0 representing none and 4 representing extreme. For each version,

five questions relate to pain, two to stiffness and 17 for function with a total of 24 questions. The maximum score for the VA3 version is 2400, and for the LK3.1 it is 96.

3.6 Functional testing

3.6.1 Timed up and go (TUG)

The TUG test assess mobility in older adults (Bennell, Dobson, & Hinman, 2011; Brooks, Davis, & Naglie, 2006; Podsiadlo & Richardson, 1991). Time taken to complete the test correlates with balance, with those taking over 14 seconds having a higher risk of falls (Shumway-Cook & Brauer, 2000).

Participants were required to rise from a seated position, walk around a cone placed three meters away and return to the seated position. Subjects were instructed to not use any arm support. Participants were given a countdown to start, and cessation of the test occurred when the individual returned to the seated start point. Each subject was given instruction, a practice trial, and two-timed tests with the best time used for analysis.

3.6.2 Four Square Step Test (FSST)

The FSST is, similarly to the TUG, used to assess mobility in older adults, having a strong correlation with the output of the TUG and is more sensitive in detecting multiple fallers (Dite & Temple, 2002).

Participants are required to negotiate a path of four squares (Figure 3.14), initially in a clockwise direction (square 1, 2, 3 then 4) then return in an anticlockwise direction (square 4, 3, 2 then 1). Both feet had to touch in each square before moving on. Each subject was given instruction, a practice trial, and two-timed tests with the best time used for analysis.

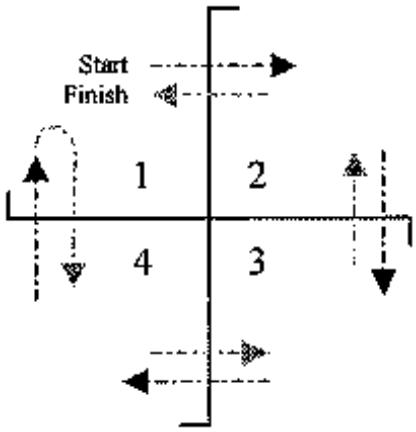


Figure 3.14 - Four Square Step Test (Dite & Temple 2002)

3.6.3 Strength

To determine strength of the quadriceps femoris group, a Biodex Multi-Joint System II (Figure 3.15) was used (Biodex Medical Systems, New York, USA). Participants were placed in an upright seated position, with their backs against the seat, knee flexed to 90º and with a strap at both the waist and mid portion of the femur. To test the strength of the muscles, knee extension was produced via further attachment to a movable arm with a strap around the lower portion of the shank.

Tests were conducted across three conditions of extension 90º per second and 180º per second (isokinetic) and isometric. In the isokinetic tests, participants were instructed to provide three maximal force extensions and for the isometric, participants were instructed to push at maximal force against the static arm for a period of five seconds. There were two practice and two test trials for each condition, with a rest period of 60s between each. Data was normalised to participant weight.

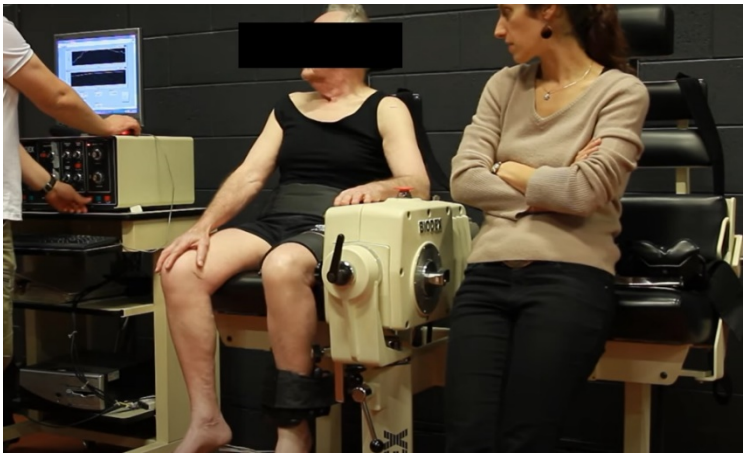


Figure 3.15 - Victoria University Biodex Multi-Joint System II with participant in capture position

3.7 Statistical Analysis

All analyses, with the exception of Chapter 6, were carried out using SPSS Version 26 (IBM SPSS Statistics) with significance level set at <0.05. Post-hoc comparison of the mean differences between groups with Bonferroni adjustment was applied to all ANOVAs. Confidence intervals and effect sizes were calculated using Cohen's d (Thalheimer & Cook, 2002). Effect sizes were classified as negligible (-0.15≤ ES <0.15), small (0.15≤ ES <0.40), medium (0.40≤ ES <0.75), large (0.75≤ ES <1.10) and very large (1.10≤ ES <1.45) and were calculated based on published literature (Thalheimer & Cook, 2002). Values were displayed in mean ± SD, except where otherwise stated.

The falls prediction model used in Chapter 6 was created in R via the use of Receiver Operating Characteristic (ROC) analysis (Hosmer, Lemeshow, & Sturdivant, 2013). In this analysis, an ROC curve is created. Within the curve, the true positive (sensitivity) is plotted against the false positive (specificity). Area under the curve values, from Hosmer et al (2013) Chapter 5, were set as no discrimination (ROC = 0.5), poor discrimination (0.5 > ROC < 0.7), acceptable discrimination (0.7 > ROC < 0.8), excellent discrimination (0.8 ≥ ROC < 0.9), and outstanding discrimination (ROC ≥ 0.9).

Chapter 4 - The effect of knee osteoarthritis and dual-tasks on stability following perturbation in an induced fall

Abstract

Older adults with knee OA are twice as likely to fall as their healthy counterparts (Levinger et al., 2011) but the exact mechanisms are not yet clear (Levinger et al., 2016). Participants were placed in an induced falling position and, from there, were required to maintain stability following release. Biomechanical data was collected and analysed using three trial types (no additional challenge, cognitive dual-task challenge and physical dual-task challenge). The outcomes from this study include older adults with knee OA had lower velocity of centre of mass, shorter step length at lower velocity, lower hip flexion angle at lower velocity, lower trunk angular velocity and lower knee flexion angle. Older adults with knee OA also had lower toe trajectory during obstacle crossing and landed their recovery foot closer to the obstacle following crossing. During cognitive dual-task trials the step time was longer, and the hip angular velocity was lower in both dual-task trial types (cognitive and physical). In relation to health status and physical function, the OA group had significantly greater body mass index, lower isometric strength, slower Timed Up and Go times, and lower physical activity levels.

The chapter will introduce the background literature in relation to stability following perturbation in older adults with knee OA including the influence of both cognitive function and obstacle avoidance.

4.1 Introduction

Older adults who fall tend to employ a strategy including the use of low velocity steps, lower muscle activation of knee extensor musculature, slower movement and greater trunk flexion angle (Barrett et al., 2012; Carty, Cronin, et al., 2012b; Carty et al., 2011). Where individuals employ such a strategy there is a higher likelihood of the centre of mass exceeding and remaining outside of, the boundary of the base of support. This leads to the employment of a multiple step strategy during stability, which is linked to increased falls risk (Carty, Barrett, et al., 2012; Carty et al., 2015; Carty et al., 2011; Maki & McIlroy, 1997, 1998). The employment of a strategy to maintain stability following perturbation involves a combination of physical skills including strength, speed, and accurate joint positioning. A successful outcome of this strategy is a single rapid long step to extend the base of support to maintain the position of the centre of mass within its boundaries. At the same time, there needs to be positioning of the upper body in a way that does not increase momentum of the centre of mass. To do so, there needs to be high knee muscle activation, faster movement and a more upright upper body (Barrett et al., 2012; Carty, Cronin, et al., 2012b; Carty et al., 2011). Further to this, there is a requirement for the lower limbs, at load acceptance following foot contact, to be able to absorb the mass of body's anterior motion while falling (Levinger, Menz, et al., 2011). In older adults with knee OA it has been reported that this group takes slower and smaller steps when recovering balance in an induced fall. This challenges their stability due to poor extension of the BOS in trials with and without dual-task interference (Downie, 2014; Levinger, Downie, et al., 2016). However, the posture of the upper body was not addressed in these works.

Posture is the positioning of the body segment relative to the gravitational vector (Winter, 1995). Control over this would logically be a vital contributor to the stability of the individual when perturbed. This is particularly important when discussing the upper body as the mass of the trunk results in two-thirds of the total mass of the body residing two-thirds of an individual's height above ground (Winter, 1995). Where the posture of this segment is not optimal this mass may be projected anteriorly, increasing risk of the rest of the body also moving forwards and thus possibly inducing a fall.

4.1.1 Influence of cognitive function on stability in older adults with knee OA

Age-related loss of cognitive function affects both processing speed, and the ability to handle multiple neural processes simultaneously (Grady & Craik, 2000). This is referred to as dual-tasking. In healthy older adults, this functional degradation influences balance due to increased body sway as well as slowed velocity when walking (van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). In dual tasks the individual is required to divide attention between both tasks, resulting in compromised stability (Posner & Rothbart, 1998), which in turn can result in a lack of appropriate postural response during a fall (Verghese et al., 2007).

The influence of cognitive performance has also been investigated in relation to its impact on falls risk in older adults with knee OA, albeit limitedly. Safe movement and control over posture requires both executive and sensorimotor function. Balance control would appear to be more demanding of cognitive function in older adults than it is in younger adults (Levinger, Nagano, et al., 2016b). In the presence of a cognitively demanding dual-task in older adults with knee OA, demonstrated via both reduced step length and lower velocity of centre of mass (Levinger, Nagano, et al., 2016b). While the influence of the lower limb would appear to create a situation of instability when cognitively challenged, there has been no investigation as to the influence of upper body posture on stability in the same conditions.

4.1.2 Influence of obstacle crossing on stability in older adults with knee OA

Tripping is one of the leading causes of falls in older adults, comprising more than 50% of total falls. Poor foot clearance while crossing the tripping hazard is implicated, as is the distance from the obstacle on landing the recovery foot following crossing (Pandya et al., 2005). In obstacle-crossing research involving recovery from static positions (Downie, 2014; Levinger, Nagano, et al., 2016b), older adults with knee OA showed reduced knee flexion and lower velocity of centre of mass when compared to controls (Downie, 2014). There was also significantly greater hip flexion, lower hip power generation and knee power absorption in the OA group when crossing obstacles (Levinger, Nagano, et al., 2016b). Again, while it appears

that a demonstrated connection exists between lower limb motion and instability while crossing an obstacle there has been no investigation of the effect of upper body posture during obstacle crossing.

Much of the discussion suggests that more anterior positioning of the centre of mass at foot contact following obstacle clearance leads to poor balance while walking. Another likely cause of poor obstacle avoidance with age is lower gait speed, shorter step and minimal clearance height with respect to the object (Tinetti et al., 1988; van Dieen, Pijnappels, & Bobbert, 2005). Where these factors are observed, there is an increased likelihood of falling (Carty, Barrett, et al., 2012; Carty et al., 2015; Carty et al., 2011) through poor control of anterior motion of the body (Grabiner et al., 1996; Grabiner et al., 1993; Pavol et al., 2001; Schultz, 1995).

In summary, research into biomechanical deficits related to stability in older adults with knee OA has to date identified limited outcomes related to balance function in this population, including spatio-temporal and strength measures. However, the influence of the upper body in stability has not yet been investigated in this population. Furthermore, in physical dual-tasking falls, there are measures not yet addressed including obstacle clearance and the landing position of the foot with respect to the obstacle.

The aims of this study were twofold:

(1) to investigate the biomechanical differences in response to perturbation

(a) between the group (control and OA)

(b) between the trial tasks (no additional challenge, cognitive dual-task challenge and physical dual-task challenge)

(3) between group and trial task.

(2) to investigate physical function in older adults with knee OA.

This research study tests the following hypothesis:(1)Older adults with knee OA across all three trial types would present a more unstable stability performance at foot contact of the first recovery step than controls. This would manifest itself in lower velocity of centre of mass, shorter step length at lower velocity, and greater trunk flexion angle.

(2) Individuals with OA would demonstrate poor physical function, in particular strength and performance in functional testing.

4.2 Methods

The study protocol was approved by the Victoria University Human Research Ethics Committee (HRE16-065). All participants were informed about the details of the study and signed a consent form before participating.

4.2.1 Study design

This study employed a cross sectional study design comparing two groups (control and knee OA) and three sets of trial conditions (no additional challenge, cognitive dual-task challenge and physical dual-task challenge).

4.2.2 Participants

A total of 63 participants participated in the study, in two groups: control (n = 15) and knee OA (n = 48).Their demographics are summarised in Table 4.1. Control participants were between 60 and 90 years old, self-ambulatory, community-dwelling and without neurological and neurocognitive deficit (further details in Chapter 3 – Methodology, section 3.3.1 Inclusion criteria). For inclusion in the OA group, participants met the National Institute for Health and Care Excellence guidelines CG177 (NICE, 2014) for the clinical diagnosis of OA, as discussed in Chapter 3 – Methodology, section 3.3.1 Inclusion criteria.

4.2.3 Data collection

Data collection was carried out as described in Chapter 3(section 3.5 Procedure). Participants were phone-screened for initial inclusion, after which they were invited to the Biomechanics laboratory at Victoria University if they met the criteria in chapter 3 (section 3.3.1 Inclusion criteria). Participants were prepared for biomechanical trials including the taking of anthropometric measures, applying

reflective markers and fitting of the body harness and belt (Chapter 3, section 3.5.1.3). Biomechanical data collection via falls recovery trials then followed. Falls recovery trials involved no additional challenge, cognitive dual-tasking challenge ((chapter 3, section 3.5.1.3.4.1), and physical dual tasking (chapter 3, section 3.5.1.3.4.2). After the biomechanical data collection was completed, participants were supplied with refreshments, at which point they completed pain assessments and assessments of function.

4.2.3.1 Biomechanical data collection

Participants completed three recovery trials following perturbation using the Tether Release Method (Chapter 3, section 3.5.1.3.4). In this method, participants were attached to an electromagnet via a belt and placed in an induced lean position until 20% of their bodyweight was measured via a vertical force transducer (Figure 4.1). When this was achieved, the power from the electromagnet was removed at random time intervals thus initiating a fall. At this point, as instructed, participants were to attempt recovery of the fall using a single step. Three stability tasks were randomly conducted for each participant:

(1) no additional challenge – stability without secondary task,

(2) cognitive dual-task – stability while counting backwards by three commencing at 100, and

(3) physical dual-task challenge – stability while stepping over an obstacle 4cm high, 1cm deep and 100cm long.

In each trial, participants were guided into the start position and instructed to put their entire body weight into the harness and to recover balance with a single step Trials would not commence until participant heels were touching the floor. Following these instructions, the electromagnet was disconnected at random time intervals. Each participant completed three trials, for each task, for each leg.

The parameters investigated for this study can be found in Chapter 3 – General Methodology (section 3.5.1.3.6).

4.2.3.2 Obstacle dimension and location during physical dual-task trials

The obstacle used in these trials was foam, 10mm wide and 40mm high (Figure 3.10), and was fixed to the floor with double sided tape in front of the feet in the induced lean position. The object's dimensions were chosen to simulate typical household obstacle height, and placement as described previously at the typical location of minimum toe clearance, approximately 500mm in front of the participant (Levinger, Nagano, et al., 2016b; Patla & Rietdyk, 1993).

4.2.3.3 Step response classification

Participant step responses to perturbation were classified as either single or multiple (Figure 4.3). A single step response included the participant extending their base of support in one step, and possibly, a second step which did not extend beyond the anterior progression of the initial recovery limb. A multiple step response involved the participant taking an additional one or more steps which extended beyond the anterior progression of the initial recovery limb (Arampatzis et al., 2008).

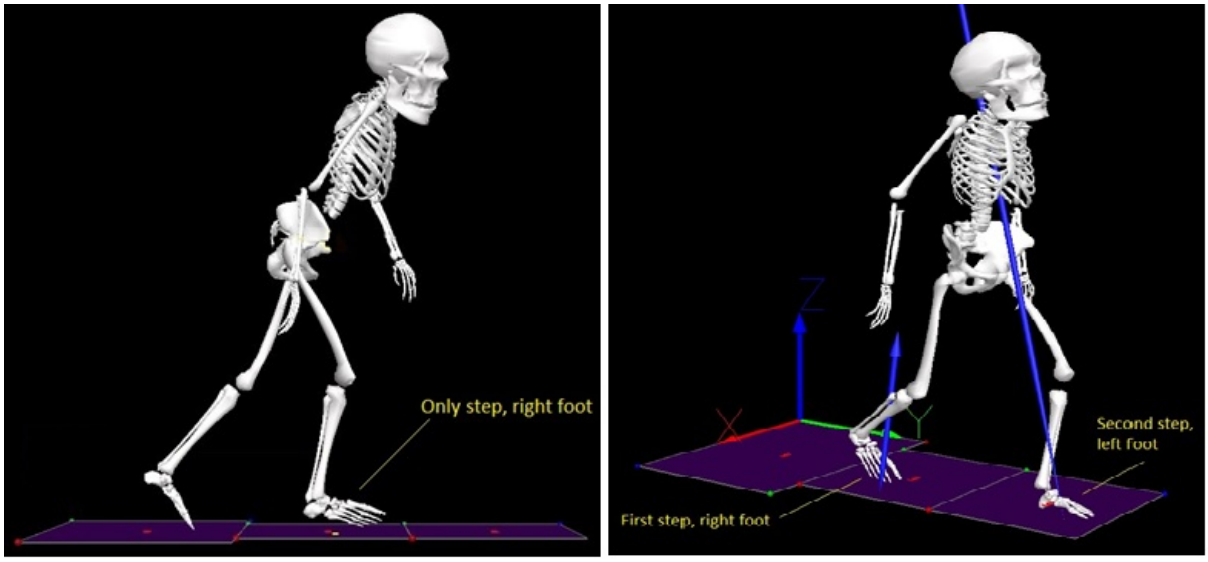


Figure 4.1 – Step responses. Single (on left) – note the right foot steps anteriorly and movement ceases. Multiple (on right) – Note the right foot steps anteriorly, followed by the left which exceeds the right foot position

4.2.3.4 Event definitions

Foot contact was defined as the first observed contact of the recovery foot with the ground by the appearance of a vector resulting from contact with the force plate(s). Where the step was not on a force plate, foot contact was defined as ankle plantar flexion over a period of three consecutive frames (0.03s) to confirm a pattern of movement (Nagano et al., 2015b). Relative head position was calculated as the difference between the anterior head marker on the same side as the toe marker on the recovery foot. Where the recovery was made with the right limb, the right head marker was used. Theleft head marker was used where left foot recovery occurred. Centre of mass position was tracked as part of the plug-in-gait model, and from this velocity of centre of mass was derived. Both margin of stability and available response time were calculated as previously described (Nagano et al., 2015a).

4.2.3.5 Toe trajectory during physical dual-task trials

Toe trajectory was determined via tracking of the toe marker on the recovery limb (RTOE or LTOE) through 100% of the swing phase (from toe off to foot contact). Group differences (control vs OA) were based on mean trajectory.

4.2.3.6 Physical function, pain, and activity data collection

The participants completed the following physical function, pain, and activity assessment tasks: Timed Up and Go (TUG), Four Square Step Test (FSST) and knee strength.

4.2.3.6.1 Timed Up and Go (TUG)

The TUG test assesses mobility in older adults (Bennell et al., 2011; Brooks et al., 2006; Podsiadlo & Richardson, 1991). Time taken to complete the test correlates with balance; those taking over 14 seconds correlated with a higher risk of falls (Shumway-Cook & Brauer, 2000).

Participants were required to stand from a seated position, walk around a cone placed three meters away and return to the seated position. Subjects were instructed not to use any arm support. Participants were given a countdown to start, and cessation of the test occurred when the individual returned to the seated start point. Each participant was given instruction, a practice trial and two-timed tests with the shortest time used for analysis.

4.2.3.6.2 Four Square Step Test (FSST)

Similar to the TUG, the FSST is used to assess mobility in older adults. There is a strong correlation with the output of the TUG and the test is more sensitive in detecting those who fall repeatedly (Dite & Temple, 2002).

Participants are required to negotiate a path of four squares (Figure 3.13), initially in a clockwise direction (square 1, 2, 3 then 4) then return in an anticlockwise direction (square 4, 3, 2 then 1), with both feet touching in each square before moving on. Each participant was given instruction, a practice trial, and two timed tests with the best time used for analysis.

4.2.3.6.3 Strength

To determine strength of the Quadriceps Femoris muscle group, a Biodex Multi-Joint System II (Figure 3.15) was used (Biodex Medical Systems, New York, USA). Participants were placed in an upright seated position, with their backs against the seat, knee flexed to 90° and with a strap at both the waist and mid portion of the femur. To test the strength of the muscles, knee extension was produced via attachment to a movable arm with a strap around the lower portion of the shank.

Tests were conducted across three conditions of extension 90º per second and 180º per second (isokinetic) and isometric. In the isokinetic tests, participants were instructed to provide three maximal force extensions and for the isometric, participants were instructed to push at maximal force against the static arm for a period of five seconds. There were two practice and two test trials for each condition, with a rest period of 60s between each. Data was normalised to participant weight.

4.2.3.6.4 Pain measures

To assess the joint pain experienced by the OA group on a daily basis the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (Chapter 3, section 3.6.1.4 Western Ontario and McMaster Osteoarthritis Index) was completed by participants in this group. As WOMAC data collection was carried out at different times, there were two methods used for collection within this tool: Visual Analogue Scale (VAS) and Likert-type scale. Each measure was calculated separately. Pain scores were compared to the maximum scores for that measure 500 for the VAS and 20 for the Likert-type scale (Bellamy, 2016).

4.2.2.6.5 Activity levels

To assess levels of physical activity the Incidental and Planned Activity Questionnaire (IPAQ) was used (Delbaere, Hauer, & Lord, 2010). This assessment includes ten questions designed to estimate physical activity in the previous week, in particular to determine how often and how long activity was undertaken. This included both planned and unplanned activity. For this chapter, the total hours per week of activity was calculated.

4.2.3 Data analysis

Data analysis was conducted as described in sections 3.7 - Data processing and 3.8 – Statistical analysis.

Demographic differences were assessed via independent t-test. Step responses, single step recovery vs multiple step recovery (two or more steps) were analysed via Chi-square test between the groups (control vs OA) and for the three trial types (no additional challenge, cognitive dual-task challenge, and physical dual-task challenge). Two-way full factorial multiple analyses of covariates (MANCOVA) were conducted to identify differences between group and trial type for the previously defined biomechanical parameters (COM_{vel}, MOS, ART, RHP, $STEP_{length}$, $STEP_{time}$, $STEP_{velocity}$, $ANKLE_{angle}$, $ANKLE_{moment}$, $ANKLE_{power}$, $KNEE_{angle}$, $KNEE_{moment}$, $KNEE_{power}$, $KNEE_{ang.vel}$, HIP_{ang}, $HIP_{ang.vel}$, $TRUNK_{angle}$, $TRUNK_{ang.vel}$) (Chapter 3, section 3.5.1.3.6), with Bonferroni-adjusted post-hoc test using BMI as the covariate. Univariate tests were conducted and reported where the interaction of the group and trial type was significant. The first trial for the condition in this study was analysed to maintain ecological validity (Lythgo, Begg, & Best, 2007; Said et al., 2009). Further ANOVAs were conducted to identify group differences in relation to functional assessment (TUG, FSST and strength). To test for any differences between group (control and OA) and step response (single and multiple) a chi-square analysis was also conducted. BMI was used as a covariate in the analysis to account for the potential effect of BMI on biomechanical parameters of stability (Blaszczyk, Cieslinska-Swider, Plewa, Zahorska-Markiewicz, & Markiewicz, 2009). No differences were noted in the biomechanical measures with this covariate. Analysis was carried out using SPSS 26 (IBM SPSS Statistics), with significance level set to < 0.05. Post-hoc comparison of the mean differences between groups with Bonferroni adjustment was applied to all ANOVAs. Confidence intervals and effect sizes were calculated using Cohen's d (Thalheimer & Cook, 2002). Effect sizes were classified as negligible (≥ 0.15 to < 0.15), small (≥ 0.15 to < 0.40), medium (≥ 0.40 to < 0.75), large (≥ 0.75 to < 1.10) and very large (≥ 1.10 to < 1.45) and were calculated based on published literature (Thalheimer & Cook, 2002). Values were displayed in mean ± SD.

4.3 Results

Sixty-six participants volunteered for this study. Two were excluded due to medical history of dementia and one passed away before commencement, leaving sixty-three participants (15 controls and 48 OA) who met inclusion criteria, and took part in the study. As noted in Table 4.1, no differences were reported in age, height or mass between the groups ($p > .05$). A higher BMI was observed in the knee OA group compared to the controls ($p = .02$). In terms of WOMAC in the VAS version subgroups, moderate pain (217.29 ± 298.90), low stiffness (55.42 ± 39.80) with a maximum score of 200, and moderate physical dysfunction (318.21 ± 250.86) were reported. Overall scores for WOMAC VAS were low (590.92 ± 518.85). In the Likert-type version low pain (5.63 ± 3.40), low stiffness (2.71 ± 1.90), and greater physical dysfunction (17.58 ± 9.15) were reported. Overall scores for the WOMAC Likert-type were low suggesting negligible deleterious effect of OA (33.54 ± 12.61).

Table 4.1 - Participant characteristics, CON and OA (mean ± SD)

		CON (n = 15)	OA (n = 48)	
		Mean ± SD	**Mean ± SD**	***p***
AGE (Year)		72.47 ± 4.81	71.02 ± 6.76	.45
HEIGHT (m)		1.70 ± 0.89	1.68 ± 0.10	.39
Mass (kg)		76.0 ± 12.28	81.9 ± 15.57	.12
BMI (kg/m^2)		***26.17 ± 3.06***	***29.10 ± 4.58***	***.02****
FEMALES (%)		4 (27%)	26 (54%)	1.00
WOMAC (VAS) (n = 24)	**pain**	-	217.29 ± 298.90	n/a
	stiffness	-	55.42 ± 39.80	n/a
	function	-	318.21 ± 250.86	n/a
	total	-	590.92 ± 518.85	n/a
WOMAC (LIKERT) (n = 24)	**pain**	-	5.63 ± 3.40	n/a
	stiffness	-	2.71 ± 1.90	n/a
	function	-	17.58 ± 9.15	n/a
	total	-	33.54 ± 12.61	n/a

*CON = control and OA = osteoarthritis, BMI = Body Mass Index, WOMAC = Western Ontario and McMaster Universities Osteoarthritis Scale, VAS = Visual Analogue Scale * significance at p <0.05, ** trend at p >.05 and <.10.*

4.3.1 Step responses

Table 4.2 shows step response (single v multiple) by groups (control and OA) across all trials (no additional challenge, cognitive dual-task challenge, and physical dual-task challenge). While relatively more OA participants responded using multiple steps across the trials, there was no difference between step response and group across all trials, (p = .12). Nor was there any difference in any individual trials including no additional challenge and cognitive dual-task challenge and physical dual-task challenge (p = .39, p = .34 respectively). During physical dual-task trials there was a trend towards more OA participants taking multiple steps (p = .09). During physical dual-task challenge trials, only the OA group demonstrated these characteristics: reported pain with a mean of 0.44 out of 10 and contact with the obstacle during five trials (10.4% of trial completions).

Table 4.2 - Step responses, by subject classification, across all trial types

		CON (n = 45)	**OA (n = 144)**	χ^2	*p*
Across all trial types	Single step (%)	23 (51%)	55 (38%)	2.36	.12
	Multiple step (%)	22 (49%)	89 (62%)		
No additional challenge	Single step (%)	6 (40%)	26 (54%)	.92	.39
	Multiple step (%)	9 (60%)	22 (46%)		
Cognitive dual-task challenge	Single step (%)	8 (53%)	12 (25%)	.92	.34
	Multiple step (%)	7 (47%)	36 (75%)		
Physical dual-task challenge	Single step (%)	9 (60%)	17 (35.4%)	**2.85**	**.09****
	Multiple step (%)	6 (40%)	31 (64.6%)		
During physical dual-task challenge trials					
Average reported pain (out of 10)		0	0.44	-	
Obstacle contact (%)		0 (0%)	5 (10.4%)	1.70	.19

Total trials CON = 45, OA = 144. CON = control and OA = osteoarthritis, **** significance at p <0.05, ** trend at p >.05 and <.10***

4.3.2 Biomechanical response to perturbation in older adults with knee osteoarthritis, compared to controls, across all trial conditions.

Table 4.3 shows the difference in biomechanical measures, including spatio-temporal and kinematic, between groups (control and OA) and the three trial types. Measures were collected at foot contact of the first step.

4.3.2.1 Differences in biomechanical response between groups, irrespective of trial type

With respect to spatio-temporal variables, the OA participants had significantly lower velocity of centre of mass ($p < .01$), and shorter step length ($p < .01$), at lower step velocity ($p < .01$) Table 4.3. The margin of stability was smaller in this group also, though not significantly ($p = .06$).

In relation to joint kinematics and kinetics the OA group across all trial types had less knee flexion angle ($p = .02$), less knee power absorption ($p < .02$), less knee angular velocity ($p = .05$), lower hip flexion angle at lower angular velocity ($p < .01$ respectively) and lower trunk angular velocity ($p < .01$).

4.3.2.2 Differences in biomechanical response between trial type, irrespective of groups

With respect to spatio-temporal variables, step time was longer for both groups in the physical dual-task trials than in both the no additional challenge and the cognitive dual-task ($p = .04$).

In relation to joint kinematics and kinetics, there was a trend to higher knee power absorption in the cognitive dual-task challenge trial compared to the no additional challenge ($p = .08$), and in the physical dual-task trial knee power was higher again than the cognitive ($p = .08$). There was also higher hip angular velocity in the physical dual-task trial than in both the no additional challenge, and the cognitive dual-task challenge ($p < .01$).

4.3.2.3 Differences in biomechanical response between groups and trial types

Knee flexion angle was significantly different between the groups and between the trial types ($p = .03$), as was knee angular velocity ($p = .02$). Univariate t-tests demonstrated significantly higher knee flexion ($p = .03$) and knee angular velocity ($p = .04$) in the OA group, in the cognitive dual-task challenge trial.

Table 4.3 - Differences in biomechanical measures between groups and trial types

	CON (n = 15) Mean ± SD			OA (n = 48) Mean ± SD			Between Groups	Between Trials	Group x Trials
	NOR	**COG**	**OBS**	**NOR**	**COG**	**OBS**			
Spatio-temporal									
MOS (m)	***0.17 ± 0.09***	***0.17 ± 0.09***	***0.14 ± 0.09***	***0.10 ± 0.16***	***0.09 ± 0.18***	***0.06 ± 0.28***	***.06****	>.10	>.10
ART (m)	0.16 ± 0.11	0.16 ± 0.10	0.12 ± 0.08	0.13 ± 0.21	0.11 ± 0.18	0.09 ± 0.32	>.10	>.10	>.10
Step length (m)	***0.40 ± 0.07***	***0.41 ± 0.08***	***0.43 ± 0.06***	***0.33 ± 0.10***	***0.31 ± 0.11***	***0.32 ± 0.16***	***<.01****	>.10	>.10
Step time (s)	***0.24 ± 0.05***	***0.27 ± 0.05***	***0.28 ± 0.05***	***0.26 ± 0.05***	***0.24 ± 0.05***	***0.28 ± 0.06***	>.10	***.04****	>.10
Step velocity (m/s)	***1.70 ± 0.34***	***1.58 ± 0.32***	***1.55 ± 0.25***	***1.30 ± 0.41***	***1.25 ± 0.38***	***1.16 ± 0.58***	***<.01****	>.10	>.10
$DISTANCE_{obs}$ (m)	-	-	***0.15 ± 0.02***	-	-	***0.10 ± 0.07***	***=.03****	-	-
TOEtrajectory.min (m)	-	-	***0.20 ± 0.04***	-	-	***0.17 ± 0.04***	***=.03****	-	-
Kinematics and Kinetics									
RHP (m)	-0.01 ± 0.15	-0.01 ± 0.11	-0.05 ± 0.12	-0.04 ± 0.14	0.04 ± 0.16	-0.10 ± 0.15	>.10	>.10	>.10
COM velocity (m/s)	***1.10 ± 0.15***	***1.09 ± 0.17***	***1.18 ± 0.15***	***0.94 ± 0.26***	***0.93 ± 0.22***	***1.01 ± 0.26***	***<.01****	>.10	>.10
Ankle dorsiflexion angle (deg)	12.83 ± 12.45	13.03 ± 11.71	11.75 ± 8.37	14.27 ± 12.85	14.20 ± 11.63	15.33 ± 11.78	>.10	>.10	>.10
Ankle moment (kgm^2/s^2)	-0.16 ± 0.54	-0.06 ± 0.26	-0.32 ± 0.48	-0.23 ± 0.38	-0.13 ± 0.37	-0.18 ± 0.48	>.10	>.10	>.10
Ankle power absorption (w)	0.80 ± 4.10	0.03 ± 0.39	1.01 ± 3.44	0.06 ± 0.88	0.10 ± 0.87	0.26 ± 1.61	>.10	>.10	>.10
Knee flexion angle(deg)	***14.45 ± 5.68***	***8.19 ± 12.71***	***15.17 ± 8.49***	***14.15 ± 12.96***	***18.65 ± 7.30***	***16.41 ± 10.00***	***.02****	>.10	***.03****
Knee moment (kgm^2/s^2)	0.42 ± 0.90	1.09 ± 4.21	0.74 ± 1.11	0.30 ± 0.97	0.38 ± 1.01	0.31 ± 1.08	>.10	>.10	>.10
Knee power absorption (w)	***-6.29 ± 6.63***	***-10.70 ± 7.43***	***-10.37 ± 5.69***	***-5.05 ± 6.79***	***-5.42 ± 5.29***	***-6.59 ± 5.73***	***.02****	***.08****	>.10
Knee angular velocity (deg/s)	***64.76 ± 36.31***	***35.58 ± 46.51***	***53.89 ± 30.36***	***57.76 ± 53.03***	***80.00 ± 38.63***	***23.83 ± 44.22***	***.05****	>.10	***.02****
Hip flexion angle (deg)	***63.56 ± 10.74***	***62.59 ± 10.33***	***60.89 ± 14.06***	***52.91 ± 12.09***	***50.78 ± 16.94***	***54.93 ± 12.31***	***<.01****	>.10	>.10
Hip angular velocity (deg/s)	***156.62 ± 56.88***	***153.45 ± 51.46***	***223.24 ± 182.19***	***87.42 ± 54.66***	***92.50 ± 57.04***	***123.79 ± 74.50***	***<.01****	***<.01****	>.10
Trunk flexion angle(deg)	22.75 ± 7.21	25.07 ± 9.60	28.57 ± 37.22	22.90 ± 15.08	25.84 ± 12.83	26.08 ± 14.85	>.10	>.10	>.10
Trunk angular velocity (deg/s)	***34.18 ± 38.19***	***41.70 ± 27.96***	***88.37 ± 267.25***	***12.75 ± 30.04***	***18.38 ± 41.98***	***8.37 ± 57.30***	***<.01****	>.10	>.10

CON = control and OA = osteoarthritis. NOR = no additional challenge, COG = cognitive dual-task challenge, OBS = obstacle/physical dual-task challenge, MOS = margin of stability, ART = available response time, RHP = relative head position **** significance at p <0.05, ** trend at p >.05 and <.10***

4.3.3 Lower limb joint kinematics during recovery step during physical dual-task trials

Figure 4.3 shows mean vertical trajectory of recovery limb the toe throughout the swing phase of the recovery limb (from toe off to foot contact). As indicated in Table 4.3, the obstacle toe clearance of the OA group was significantly lower at the point of obstacle crossing.

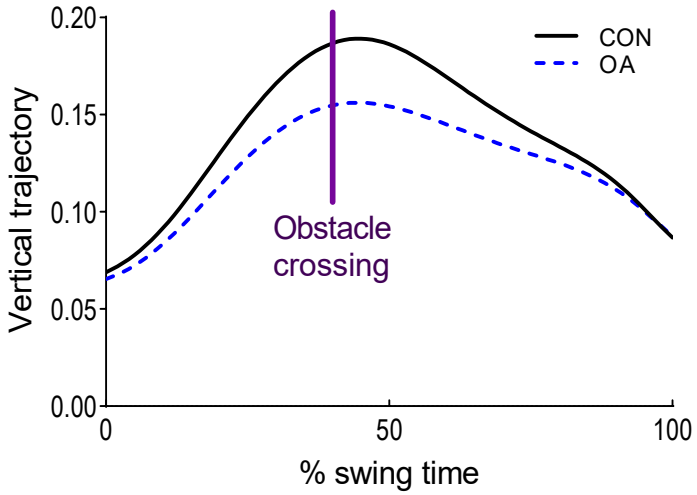


Figure 4.2 - vertical trajectory of recovery limb toe. Lines: solid black = control, dash blue = Osteoarthritis, vertical purple = average crossing time (expressed as % of swing time for recovery limb)

Figure 4.4 shows lower limb joint kinematics throughout the swing phase of the recovery limb (from toe off to foot contact). At foot contact, as indicated in Table 4.3, ankle and knee measures were the same between groups whereas the hip was more flexed in the OA group. At obstacle crossing, the OA group was more dorsi-flexed at the ankle, more extended at the knee and had similar flexion at the hip.

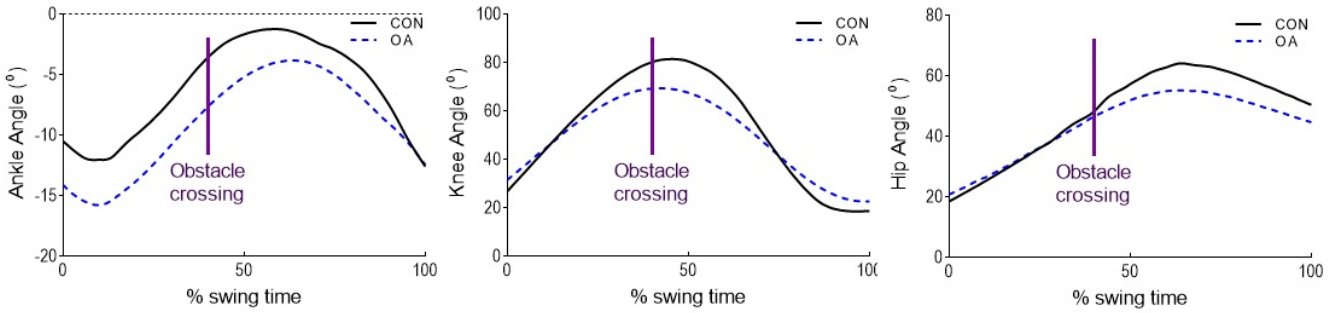


Figure 4.3 – Group (control and OA) average angles for ankle, knee, and hip throughout the step. Lines: solid black = control, dash blue = Osteoarthritis, vertical purple = average crossing time (expressed as % of swing time for recovery limb)

4.3.4 Measures of strength, function and physical activity

Table 4.4 presents a comparison of strength, function, and physical activity between older adults with knee OA and healthy, age-matched controls. Participants in the OA group completed the Timed Up and Go significantly more slowly ($p = .01$, large effect size) than controls. In the Four Square Step Test there was no difference in performance between the groups. At both 90º per second and 180º per second there was no difference in torque between the groups however during Isometric contraction, the OA group produced significantly less torque ($p < .01$, large effect size) than the control group. Finally, OA participants had significantly lower total physical activity levels ($p < .01$, large effect size) than controls.

Table 4.4 - Measures of Strength, Function, and Physical Activity by group (mean ± SD reported)

	CON (n = 15)		OA (n = 48)			
	Mean ± SD	**95% CI**	**Mean ± SD**	**95% CI**	**ES**	***p***
TUG (s)	***7.04 ± 1.01***	***6.48, 7.60***	***8.24 ± 1.71***	***7.74, 8.74***	***.85***	***.01****
FSST (s)	8.45 ± 1.22	7.78. 9.13	8.62 ± 1.55	8.17, 9.07	.12	.70
Isotonic Strength (90º) (Nm)	6.60 ± 1.58	5.73, 7.48	6.32 ± 2.54	5.58, 7.05	.13	.68
Isotonic Strength (180º) (Nm)	4.88 ± 1.29	4.17, 5.59	6.00 ± 3.00	5.13, 6.87	.49	.17
Isometric Strength (Nm)	***8.70 ± 2.31***	***7.42, 9.98***	***6.92 ± 1.89***	***6.37, 7.47***	***.84***	***<.01****
IPAQ (Total hours/week)	***37.84 ± 20.78***	***26.33, 49.35***	***23.85 ± 13.04***	***20.07, 27.64***	***.81***	***<.01****

CON = control and OA = osteoarthritis, TUG = Timed Up and Go, FSST = Four Square Step Test, IPAQ = International Physical Activity Questionnaire, ***
significance at p <.05 ** trend at p >.05 and <.10

4.4.1 Summary of main findings

The aims of this study were to investigate: (1) the group main effect and interaction in the biomechanical measures between groups (OA and control) and between trial conditions (no additional challenge, cognitive dual-task challenge, and physical dual-task) during forward induced falls, and (2) the differences in physical function (strength and balance) in people with knee OA compared to age-matched controls.

In (aim 1), when compared to the biomechanical measures in the control group between groups in all trials, the OA group showed lower velocity of centre of mass, less available response time, shorter step length at lower step velocity, and reduced knee power absorption. Between trial types, all participants in dual-task trials exhibited slower step time. There was lower knee power absorption in both cognitive and obstacle conditions, and lower hip angular velocity also in both cognitive and obstacle conditions. Between groups and trial types the OA group had higher knee flexion angle in the cognitive dual-task challenge than in the trial with no additional challenge, the OA group had higher knee flexion in the physical dual-task than in the trial with no additional challenge, and the OA group had higher knee angular velocity in the cognitive dual-task challenge.

In relation to aim 2, the knee OA group, when compared to controls, demonstrated poor quadriceps strength, slower times in a TUG test, and lower total physical activity level.

4.4.2 Participant demographics

The demographics of the cohort in this study were similar but there were a greater number of males within the controls and a balance in genders within the OA group. This may appear divergent to the established expectation of women being at greater risk of developing the condition (Felson, 2006; Guccione et al., 1994). It is of note that the BMI of the OA group was significantly higher than that of the controls.

BMI is often linked to knee OA with increases in mass being significantly related to development of the condition (Felson, 1996; Felson, Anderson, Naimark, Walker, &

Meenan, 1988; Holmberg, Thelin, & Thelin, 2005; Manek, Hart, Spector, & MacGregor, 2003; Zhou, Liu, Chen, & Liu, 2014). Even where increases are within what might be considered normal weight gain there is amplified risk of development of OA (Holmberg et al., 2005) and meta-analysis shows that as little as a 5-unit increase in BMI significantly increases the risk of OA (Jiang et al., 2012). Higher BMI has a number of functional impacts on older adults with knee OA, including lower knee extension in late stance of gait, and shorter steps at lower velocity (Harding, Hubley-Kozey, Dunbar, Stanish, & Astephen, 2012). In this study BMI was used as a covariate to account for any potential impact of the variable on participants' stability. It was observed that there was no deleterious influence from body mass on any biomechanical variable within this study.

4.4.3 Group influence on biomechanical response to perturbation

Regardless of task, there were several biomechanical variables that impacted on the OA group's ability to recover balance in a stable manner. During trials, the OA group had reduced margin of stability, lower velocity of centre of mass, shorter step length, lower step velocity, lower hip flexion angle and lower hip angular velocity.
Lower margin of stability may reflect an inability to control motion of the centre of mass and to keep it within the base of support. Where individuals fail to do this, multiple steps are required to re-establish control over the centre of mass motion. This process increases risk of falling (Carty et al., 2011). While not significant, the available response time in the OA group was shorter than that for the controls. From these variables there is an emerging picture of a lack of capacity to halt forward motion of the body. This is supported by knee kinetics at first foot contact of the recovery limb, which show reduced power absorption on landing, and may lead to further inability to control the motion of the centre of mass as it moves anteriorly. In otherwise healthy older adults, poor control of dynamic stability may arise when poor strength leads to inability to extend the base of support effectively when falling (Karamanidis et al., 2008). In older adults with knee OA, it is possible that strength is further impaired, which would lead to additional difficulty in extending the base of support (Levinger, Nagano, et al., 2016b). In this study, the OA group took short and

slow steps following perturbation. This finding is implied in ineffective extension of the base of support via the lower margin of stability despite the lower velocity of centre of mass. As the power absorption of the knee at foot contact was also compromised the participants may not be able to overcome the observed lower margin of stability, particularly where the posture of the upper body is further forward. While the positioning of the upper body is not further forward in the OA group, the reduced angular velocity of the hip might highlight a potential reason for poor stability in the OA group. In this case, slower flexion of the hip might mean that the anterior position of the upper body mass is present for long enough that the participant was not be able to control anterior motion (Pavol et al., 2001).
Interestingly, while a comparatively higher number of OA participants took multiple steps, compared to controls, the finding was not significant (Table 4.2). This may suggest that there are other influences, beyond participant classification that impact the biomechanics of stability.

4.4.4 Trial type influence on biomechanical response to perturbation

In the case of this study, in the cognitive trial type there were slower and lower spatio-temporal variables, presumably because of the impact on cognitive function that led to slower, and less anterior, recovery limb movement.

Cognitive performance decline is associated both with difficulty in performing routine physical tasks (such as standing, walking and grabbing with the hand), and with attention demanding physical tasks (such as balance, single leg stance and tandem stance) (Tabbarah, Crimmins, & Seeman, 2002). This association shows that cognitive performance plays a core role in execution of physical tasks, in particular via the communication between body systems most responsible for balance (Tabbarah et al., 2002). Where there is a challenge to this communication, there is a concomitant deficit in ability to execute tasks which control balance.

Poor performance in obstacle crossing is linked to increased falls risk. In older adults there is a noted decrease in both step length and velocity when stepping over an obstacle (Chen et al., 1991). Reduced step length while crossing an obstacle increases the risk of contact (Chou & Draganich, 1998), and increases the risk of

falling as a result. Following foot contact, ideal control of anterior motion of the body during a fall would have the individual ceasing movement via activity at the lower limb joint: the ankle, knee and hip. Cessation of movement in a fall requires production of forces greater than that of the falling body. These forces are increased when crossing an obstacle. The stepping limb uses greater elevation as it crosses the object and therefore descends from a higher position with greater momentum (Levinger, Nagano, et al., 2016b). Older adults who fall sometimes demonstrate inadequate triceps surae strength to achieve this (Judge et al., 1996; Melzer, Benjuya, Kaplanski, & Alexander, 2009) and, as a result, may compensate with hip flexor power to achieve the required control of anterior motion (Judge et al., 1996). As the elevated stepping limb is lowering at greater momentum than would be the case in non-obstacle trials, arresting this necessitates greater joint powers to absorb impact (Levinger, Nagano, et al., 2016b). In relation to the lower limb, ankle power in the OA group was lower than that of the controls. At the hip, however, the OA group had significantly less flexion (52.91^{o} compared with 63.56^{o}) and also significantly lower angular velocity (123.79^{o}/s compared with 223.25^{o}/s). While hip flexor power was not assessed in this study, the lower angular velocity noted in this group may have negatively influenced the activity of the hip flexors. Given the formula for power of a body that is angularly accelerating ($P = T\omega$), it would be reasonable to assume low hip flexor power arises from significantly lower angular velocity (ω). The slower speed of change in hip angle leads to lower power at the joint. This could explain the lack of control of the anterior movement of the centre of mass at foot contact, resulting in the taking of multiple steps.

The findings in this thesis are similar to earlier works (Levinger, Nagano, et al., 2016b) which suggested that lower velocity of centre of mass in the cognitive dual-tasking trial was a result of cognitive demand. However the cause of the higher velocity of centre of mass in the obstacle trial compared with that in the normal trial, however, remains unclear. Perhaps the higher velocity of centre of mass during obstacle crossing is a result of the increased anterior shift in mass associated with the rapid elevation of the stepping limb in an attempt to clear the obstacle, which in turns leads to increased falling momentum at foot contact. While previous studies in knee OA have shown similar minimum toe clearance to that of controls during gait (Levinger, Lai, et al., 2012), to date there has been no investigation into clearance in

recovery from a static forward lean. This may be the first study to identify the trajectory of the toe throughout recovery limb swing phase in falls from induced leans in older adults with knee OA.

4.4.5 Interaction, between groups and trial type, in biomechanical response to perturbation

Knee flexion angle, knee angular velocity, hip flexion angle and trunk angular velocity were the only biomechanical parameters showing interaction between groups and trial types in this study. In the OA group, the angle of the knee, at contact of the recovery foot was smaller only in the normal trial and larger in both the cognitive and physical dual tasks, particularly in the former dual task.

The findings related to the knee were different from that of previous research dealing with recovery from induced leans in OA (Levinger, Nagano, et al., 2016b) in which the OA group had smaller knee flexion angle in all trial types. Furthermore, the angles of flexion in the Levinger et al (2016) work were larger in all trials, for all groups, than noted in the current study. In the study of Levinger et al (2016) joint kinematics were measured at peak knee flexion whereas in this study, kinematics were measured at foot contact (defined using changes in ankle plantar flexion over subsequent motion capture frames). Collecting data at the foot contact was done to allow for inclusion of participants who, in steps following the first, were not stepping on force plates cleanly, for example a second or third step that was more lateral. Regardless of variation in results, the OA group in this study was able to produce knee flexion angles greater than that of controls in both dual-tasking trial types. The dorsi-flexion of the ankle and knee flexion were greater in the OA group during dual-task trials. In the case of the present study, the OA group did not have severe symptoms and, hence, may not have restriction in ability to produce knee flexion. With respect to knee angular velocity, where there was no extra challenge in stability the velocity of the knee angle change was lower in the OA group than in controls. In the dual-task trials, however, there is a wide variation in performance. In the cognitive trial the knee angular velocity is higher in OA and in the physical dual-task it is lower. It is not clear why this variation exists; but it is possible that the extra demands of attention associated with tasks secondary to stability (Levinger, Nagano,

et al., 2016b) may increase variability in joint motion. These demands of attention arising from the cognitive trial type would appear to have a deleterious effect on communication between the relevant systems tasked with movement control, in particular the pre-motor cortex (Tabbarah et al., 2002). The negative influence on communication may manifest itself in poor trunk motor control via the observed lower angular velocity of this segment.

In this study, hip and trunk kinematics in the OA group showed a far more extended position of the upper body than in the controls group which may suggest a more guarded position with respect to possible pain in other joints such as the back. Knee and back pain are predictors of dysfunction (Hirase, Makizako, et al., 2020; Hirase, Okubo, Menant, Lord, & Sturnieks, 2020) and individuals with unspecified back pain appear to maintain an upright posture (Jones, Henry, Raasch, Hitt, & Bunn, 2012). Such an approach has been shown to produce shorter and slower steps in stability (Hirase, Okubo, et al., 2020) - a noted factor in increased falls risk. The combination of hip and trunk measures appears to suggest a more controlled upper body posture in the OA group, which might be expected to counteract the influence of the lower limb on dynamic posture. This is difficult to argue though, as the lower hip angle may well be connected to the shorter step being taken in the OA group (Judge, Davis, & Ounpuu, 1996). While it might well be contended that the upper body posture of OA participants is safer in terms of anterior motion control, the positioning of the COM, together with taking a shorter and slower recovery step, might be the reason for instability regardless of upper body posture.

4.4.6 Pain and decline in physical function in knee OA

In this study, the pain level in the OA group was moderate in the VAS and low in the Likert scale suggesting mild symptoms across the groups. Further to this, the assessments of both stiffness, and impacts on daily function arising in the WOMAC results suggest low influence of pain in this sample. In relation to function, the performance of the OA participants in the TUG was significantly lower than in the controls group, suggesting poorer function in the OA group. With respect to strength, the OA group produced significantly less strength in the isometric condition, while

producing the same strength in both of the isokinetic conditions. Finally, the knee OA group was significantly less physically active than for the controls group.

Pain has been noted as a predictor of dysfunction in OA (Adegoke, Babatunde, & Oyeyemi, 2012; Alencar et al., 2007; Dekker, van Dijk, & Veenhof, 2009; Foley et al., 2006) and is also associated with increased falls risk (Arden et al., 1999; Felson et al., 1987; Hirase, Okubo, et al., 2020; Leveille et al., 2002; Leveille et al., 2009; Munch et al., 2015; Volpato, Leveille, Blaum, Fried, & Guralnik, 2005). The mechanisms for the relationship between pain and falls can be seen via one of three main foci: joint pathology, effect of pain on the neuromuscular system, and the effect of pain on cognition (Leveille et al., 2009). The resulting pain from joint damage in OA is problematic as there is poor correlation between discomfort and disease progression (Dieppe, 2004). The effect on the neuromuscular system may arise from reflex muscle inhibition (Graven-Nielsen, Lund, Arendt-Nielson, Danneskiold-Samsoe, & Blidda, 2002), leading to weakness of lower limb muscle or slower motor unit response in a fall (Leveille et al., 2009). The neuromuscular influence may also be a central effect on cognition which may arise from distraction which interferes with a falls response (Leveille et al., 2009). This reflects other works relating to pain in OA, suggesting that intermittent and intense pain, rather than low discomfort, was had the most impact on everyday life (Hawker et al., 2008). While pain is associated with notable and ongoing reductions in physical function generally (Jinks, Jordan, & Croft, 2007), it should be noted that symptoms of pain do not necessarily correlate well with severity of OA specifically (as determined by radiographic imaging) (Dieppe, 2004).

Poor performance in functional measures such as TUG are linked to increased falls, particularly where time taken to complete exceeds 14 seconds (Arnold & Faulkner, 2007; Medell & Alexander, 2000). Further to this, the TUG is used to measure functional capacity in those taking multiple steps during a fall (Levinger, Downie, et al., 2016). This might suggest mobility and balance deficit while in motion. Performance in the FSST, however, is a more sensitive measure of balance when standing (Moore & Barker, 2017). In this study the OA participants also completed the test more slowly than did controls, though not significantly. This may mean that older adults with knee OA are more at risk of falling in motion than when standing, but larger studies would be needed to confirm this.

People with knee OA have been reported to have weaker lower limb muscle compared to asymptomatic older adults (Espinosa, Costello, Souza, & Kumar, 2020; McAlindon, Cooper, Kirwan, & Dieppe, 1993; Vassão et al., 2020). In particular, poor quadriceps femoris strength has been commonly reported in older adults with knee OA (Berger et al., 2012; Culvenor, Wirth, Roth, Hunter, & Eckstein, 2016; de Zwart et al., 2015; Levinger, Downie, et al., 2016). The outcomes in this study were supported by the large effect size, suggesting a lower strength within this group, thus confirming the trend ($p = .09$, large effect size) noted in earlier works (Downie, 2014). It is unclear why differences between the groups were demonstrated in the isometric strength but not in the isokinetic strength. It may be that the OA group is unable to reach forceful contraction when the leg is stationary but further studies would be needed to confirm this. The results from this study differ from previous works which report lower extensor performance, particularly in the case of older adults who have self-reported functional deficit (Berger et al., 2012), in older adults who are fallers (de Zwart et al., 2015), or in males only (Culvenor et al., 2016). While the differences between the present study and others would appear to cloud the issue around strength in OA, there are several possible explanations that may illuminate the discrepancies. Berger (2012) noted that extensor maximum voluntary contraction was not uniform across all the spectrum of OA function, making it hard to determine the actual influence of low strength arising from the condition. Variability in joint condition (such as excess fluid), pain level, and individual activity reduction due to OA can also influence the association between strength and progression of OA (Culvenor et al., 2016). The lack in difference between participants with knee OA and asymptomatic controls in the isokinetic strength in the present study may suggest that older adults with knee OA are capable of the same extensor strength as asymptomatic older adults. However, the lack of variation in this sample may also explain the results and further studies may be needed to confirm this outcome.

Lastly, lower levels of physical activity predispose community-dwelling older adults to increased falls risk (Levinger, Downie, et al., 2016; Skelton, 2001). Where older adults are not as active, there is a noted loss of balance, partially arising from a lack of confidence in their ability to be stable when perturbed (Stubbs, West, et al., 2014). Physical activity is paramount in those with OA who wish to maintain independence (Dunlop, Manheim, Yelin, Song, & Chang, 2003; Wang, Helmick, Macera, Zhang, &

Pratt, 2001). Lower physical activity is “significantly associated with poor physical function” (Lee et al., 2015). The findings in this work are similar to those of previous research into older adults with knee OA showing lower total physical activity (Herbolsheimer et al., 2016; Song et al., 2018; Watanabe et al., 2010). The low level of physical activity in older adults with knee OA may be related to two key points, increases in pain and BMI-associated OA (Rosemann, Kuehlein, Laux, & Szecsenyi, 2008). The presence of pain and associated discomfort may be related to a reduction in physical activity due to mechanical or psychosocial barriers (Dieppe, 2004). Mechanical barriers may relate to limited knee range of motion, whereas psychosocial barriers might include deterrence from activities that are perceived to exacerbate symptoms (Manlapaz et al., 2019). Both of these factors are likely to increase pain experience, resulting in avoidance of physical activity.

4.4.7 The effect of knee OA on step response

In this study, there was no difference with respect to the step responses employed by either group (single or multiple) between the control and OA groups.

In order not to fall, individuals must employ a response which involves taking a single step of sufficient length and velocity, in order to extend the BOS so that the COM is maintained within its boundary. This single step recovery places the participant at lower risk of falling than does a multiple step response via the rapid extension of the BOS, and therefore the encapsulation of the COM (Barrett et al., 2012; Carty, Barrett, et al., 2012; Carty, Cronin, et al., 2012b). Additionally, when perturbed, the individual must control their posture in order to create the most ideal positioning of limbs in order to avoid a fall. That is to say, they must align their body segments in such a way as to maintain their relative mass about the gravitational vector (Winter, 1995). This ideal placement aids in the control of whole-body mass when in motion. As discussed previously (Chapter 2, section 2.3.1), high velocity single step responses are seen as stable particularly when compared to the unstable response taking multiple slow steps and not controlling posture which results in a lack of maintenance of the COM position within the BOS.

The findings in this study are unexpected as one might speculate the OA group to be more likely to take multiple steps. However, given the relatively small sample size in this study, the results may not be entirely representative of the population, and a larger sample size might be required to confirm the findings.

4.5 Conclusion

The hypotheses for this study were that (i) older adults with knee OA would, across all trial types, present as more unstable than age-matched controls due to lower velocity of centre of mass, shorter step length at lower velocity and greater trunk flexion angle. And (ii) individuals with OA would demonstrate poor physical function, in particular strength and performance in functional testing. The outcomes from this study partly support both, in that older adults with knee OA demonstrated reduced spatio-temporal measures, but no difference in upper body posture, resulting in no difference in stability.

The effect of the step length and velocity variables results in limited extension of the base of support and therefore results in a smaller margin of stability in the OA group. This would support an assertion of poor stability in this group, despite lower velocity of centre of mass. Contrary to this, the OA group maintained a more upright position of the upper body which would appear to alleviate the deleterious effects of the lower limb on centre of mass motion. While the OA group across all trials was statistically no more likely to take multiple steps during recovery following perturbation, stability in this group remains somewhat challenged via activity in the lower limb. This is particularly evident in dual-task trials, where poor knee power absorption was lower in the OA group. Finally, demonstration of unstable response in older adults with knee OA is achieved in variability of knee kinematics in dual-task trials in particular. Knee flexion angle is greater in more complex challenges, and the change in angle of the knee is slower in the physical trial than it is in the cognitive.

Chapter 5 - The impacts of pain and executive function on stability in older adults with knee osteoarthritis

Abstract

Knee pain is a leading symptom of the onset of OA, particularly during load bearing movements (Michael et al., 2010). Alongside pain, executive function has been associated with poor physical function in older adults with knee OA (Morone et al., 2014). While both are researched in connection to OA, neither have been investigated in relation to the biomechanics of falls in this group. This chapter focuses on determining relationships between pain and executive function and common biomechanical measures of instability identified in Chapter 4 of this thesis. The outcomes of this study include moderate positive correlation between fear of severe and total pain, both with increased hip angular velocity. In relation to executive function, there was no correlation between any functional measure and biomechanical factors.

5.1 Introduction

The connection between pain and stability (section 2.3.1 Defining balance and stability) would appear to be linked to the activity during assessment, as well as the physical condition of the participant. During quiet stance, for example, and where pain is induced in asymptomatic subjects there seems to be no deleterious effect on balance (Bennell & Hinman, 2005), but in the presence of knee OA there is reported increased sway (Hassan et al., 2001). In dynamic stance, by contrast, while there is some impairment to stability in the presence of pain there is little correlation between the perception of discomfort and balance function (Hinman et al., 2002). Only one study, to date, has investigated pain and dynamic stability following perturbation (Levinger, Downie, et al., 2016), and found that there was no difference in step response, single versus multiple, following perturbation in older adults with knee OA compared to asymptomatic controls. The employment of a multiple step strategy following perturbation is unstable (Chapter 2, section 2.3.1) and increases falls risk

for the individual (Carty, Cronin, et al., 2012a; Carty et al., 2015; Carty et al., 2011; Maki & McIlroy, 1997, 1998). While pain would not appear to negatively affect stability, it should be noted that the Levinger et al (2016) did not address the spectrum of pain, including type, fear and catastrophising, and physical effect of particular types of pain (neuropathic or nociceptive).

The role of executive function in stability (section 2.3.1 Defining balance and stability) has also been argued based on the activity being assessed. During gait, for example, there is a strong relationship noted between poor executive function and poor physical function, including slowed response, increased stride variability and slowed stepping (Hausdorff et al., 2006; Holtzer, Verghese, Xue, & Lipton, 2006). In quiet stance, poor executive function is associated with increased sway (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997), and in dynamic there are links between poor Berg Balance scores and low scores on executive function testing including Trail Making and Stroop. In otherwise healthy adults, poor executive function links to slower Trail Making Test times (Voos, Custódio, & Malaquias, 2011), and in post-stroke poor executive function links to poor Stroop scores (Liu-Ambrose, Pang, & Eng, 2007). It would appear that executive function, as well as attention, is an important factor in gait, posture, and balance (Buracchio et al., 2011) and, while older adults with knee OA appear more effected in these areas than asymptomatic older adults, no studies to date have investigated any possible connection.

The aims of this study were to, i) determine the relationship between pain level and common biomechanical measured of instability noted in older adults with knee, and ii) determine the relationship between executive function and common biomechanical measured of instability noted in older adults with knee OA. The common biomechanical measures were being identified in Chapter 4 of this thesis. The hypotheses being that:

1. Higher pain in older adults with knee OA would correlate with unstable balance response via, lower velocity of centre of mass, shorter step and lower step velocity, smaller hip flexion angle, and lower hip angular velocity

2. Poorer executive function in older adults with knee OA would correlate with unstable balance response via, lower velocity of centre of mass, shorter and lower velocity step, smaller hip flexion angle, and lower hip angular velocity

5.2 Methods

The study protocol was approved by the Victoria University Human Research Ethics Committee (HRE16-065), and all participants were information about the details of the study and signed a consent form before participating.

5.2.1 Study design

A correlational study design was employed to investigate relationships between pain and executive function measures, and biomechanical measures identified as being unstable arising from Chapter 4 of this thesis.

5.2.2 Participants

A convenience sample of 24 participants chosen for their community dwelling status and willingness to participate in a longitudinal study (Chapter 6) took part in the study, their demographics are summarised in Table 5.1. Inclusion criteria included age between 60 and 90 years old, self-ambulatory, community dwelling and without neurological and neurocognitive deficit. With respect to presence of OA, participants were included if they met the National Institute for Health and Care Excellence guidelines CG177 (NICE, 2014).

5.2.3 Data collection

Data collection was carried out as described in Chapter 3 – Methodology, section 3.6 Procedure. To determine final inclusion in this study, participants underwent a St Louis University Mental Status Examination (5.2.3.1) and, following successful conclusion, completed pain and executive function assessment (5.2.3.2, and 5.2.3.3).

5.2.3.1 St Louis University Mental Status Examination

The St Louis University Mental Status Examination (SLUMS) (Tariq, Tumosa, Chibnall, Perry III, & Morley, 2006) (Appendix 4) is an assessment designed to detect dementia and mild cognitive disorder. Through the SLUMS assessment, clinicians create a final score to determine if there is presence of dementia or mild cognitive disorder in the patient. The maximum score for the SLUMS exam is 30, with performance levels within this score related to highest education completed by the subject. For those who have completed High School, normal neurocognitive function is recognised by a score of 27 and above, mild neurocognitive impairment between 21 and 26 with dementia between 1 and 20. For those with less than a High School education, normal neurocognitive function is noted by a score of 25 and above, mild neurocognitive impairment between 20 and 24, and dementia between 1 and 19.

5.2.3.2 Pain data collection

Pain data collection was conducted while participants received refreshments following biomechanical data collection. Participants were then relaxed and completed questionnaires by themselves following explanation from the researcher.

5.2.3.2.1 Brief Pain Inventory – Short Form

The Brief Pain Inventory – Short Form (BPI-SF) (Cleeland, 2009) (Appendix 9) is a tool to assess clinical pain. It allows for participants to rate both their level of pain, and the extent to which that pain interferes with both feeling and function. Through the assessment of these items, the BPI-SF can determine both the severity of, and interference from, pain. When these are combined, the test affords the ability to assess the pain experience of the individual with higher scores associated with more pain severity and interference. The questionnaire is a 10-point Likert-type scale, ranging from zero (absence of pain) to 10 (worst pain imaginable). Subjects are able to show location of pain, and rate that pain in the previous 24-hour period as well as

at the time of assessment. Following this, the participant can outline pain treatment, including any relief arising. Finally, the assessment includes level of interference from pain in general, on mood, on work, on relationships, on sleep and enjoyment of life.

5.2.3.2.2 PainDETECT

PainDETECT (Freynhagen, Baron, Gockel, & Tolle, 2006) (Appendix 10) is a questionnaire, designed to detect the influence of neuropathic pain, or pain associated with damage with the nervous system. Originally developed to better understand lower back pain, it allows for participants to describe their pain, and for clinicians to determine the type of pain experienced by the responder. The questionnaire uses a 10-point Likert-type scale to describe pain at the time of assessment, the strongest over the past month as well as the average for the same period. There are also questions relating to the course of pain and on pain sensation (using a six-point Likert-type scale). The score range is zero to 35. Through the PainDETECT assessment, clinicians create a final score to determine if the pain is Nociceptive (arising from tissue damage), Neuropathic (arising from nervous system damage), or unclear.

5.2.3.2.3 Fear of Pain Questionnaire

The Fear of Pain questionnaire (FPQ) (McNeil & Rainwater, 1998) (Appendix 12) is an instrument designed to allow clinicians to better understand fear and anxiety of patients experiencing pain. It includes questions using a five-point Likert-type scale, in subsets addressing fear of severe (score range of zero to 50), minor(score range of zero to 50), medical/dental (score range of zero to 50), and total fear of pain (score range of zero to 150).

5.2.3.2.4 Pain Catastrophising Scale

The Pain Catastrophising Scale (PCS) (Sullivan, 2009) (Appendix 13) was designed as an instrument to evaluate patients catastrophic thinking as it relates to pain. Completion of the PCS allows for clinicians to understand how patients think about pain, via the addition of scores for each domain within the assessment. Higher scores suggest more negative thinking with respect to pain. Each question is responded to via a Likert-type scale from zero to four across three subsets: rumination (score range from zero to 16), magnification (score range of zero to 12), helplessness (score range from zero to 24), and a total catastrophising score (range from zero to 52).

5.2.3.2.5 Western Ontario and McMaster Universities Osteoarthritis Index

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (Bellamy, 2016) (Appendix 11) is a group of questionnaires used by clinicians to assess osteoarthritic pain, stiffness and physical function. The WOMAC final score provides clinicians with a tool to assess relative level of limitation arising from the onset of Osteoarthritis in the patient with higher scores showing greater impost from the condition. The Likert-type (LK3.1) version of the tool was used for the present study. In this version, participants tick a box with their choice of response; none, mild, moderate, severe, or extreme. This provides a score ranging from zero to four for each question, with zero representing none and four representing extreme. For each version, five questions relate to pain, two to stiffness and 17 for function with a total of 24 questions. The maximum score for the LK3.1 it is 96.

5.2.3.3 Executive Function assessments

5.2.3.3.1 Trail Making Test A & B

The Trail Making Test (TMT) (Army, 1944) (Appendix 6) is an assessment, originally designed to determine general intelligence, that has become associated with clinical

assessment of brain impairment including executive function (Tombaugh, 2004). Through the TMT assessment, clinicians create a final score (based on total time for both parts) to determine the level of performance in areas including visual searching, processing speed, mental flexibility and executive function (Tombaugh, 2004).

Both A and B subsets were administered according to the guidelines (Spreen & Strauss, 2006). For variant A, participants were instructed to draw a line between numbered circles in ascending order, without lifting the pen from the paper, in the quickest time possible. For variant B, participants were instructed to draw a line between alternating numbered and lettered circles in ascending order, again without lifting the pen from the paper. Where mistakes in either subset were made, participants were instructed to return to their previous circle and move forwards from that point. The time taken for each subset was recorded, and interpreted as the total time for completion of both parts (Bowie & Harvey, 2006).

5.2.3.3.2 Stroop Colour and Word Test

The Stroop Colour and Word Test (Golden, 1978) (Appendix 7) is an assessment designed to measure cognitive performance based on interference from external stimuli. Through the Stroop assessment, clinicians create a final score (based on total time for all three parts) to determine the level of interference from external stimuli.

This test was administered according to guidelines (Golden, 1978), with participants instructed to complete the assessment as quick as possible. The time taken for each test was recorded, and the final score was the total time for all three parts.

5.2.3.3.3 Wechsler Memory Scale III Digit Span

Wechsler Memory Scale-III Digit Span subtests measure the participants attention and working memory (Wechsler, 1945). In this assessment (Appendix 8), participants memorise numbers read to them and repeat them back to the tester one number at a time. Following each successful repetition, the subsequent number

increases by one digit to make the memory more complex. There are two sets of repetition within the test, forwards (measuring attention) and backwards (measuring working memory).

The test was administered according to guidelines (Wechsler, 1945) with the total number of successful repetitions of numbers recorded and interpreted as a single summary value representing working memory performance (Fink et al., 2014).

5.2.4 Statistical analysis

Analysis of collected data was carried out, as described in Chapter 3 – Methodology, sections 3.7 - Data processing and 3.8 – Statistical analysis.

The parameters investigated for this study arose from the common biomechanical measures affecting step response (arising from Chapter 4), and included:

I. COM_{vel} – velocity of the COM in the anterior direction
II. $STEP_{length}$ – length taken in first recovery step (Fig. 5.1)
III. $STEP_{vel}$ – $STEP_{length}/STEP_{time}$. The speed of the recovery step.
IV. HIP_{ang} – angle of the hip between the trunk segment and thigh, assuming 0^{o} as upright stance, (Fig. 5.2),
V. $HIP_{ang.vel}$ – $\Delta HIP_{ang}/STEP_{time}$. The speed of the hip angle change.

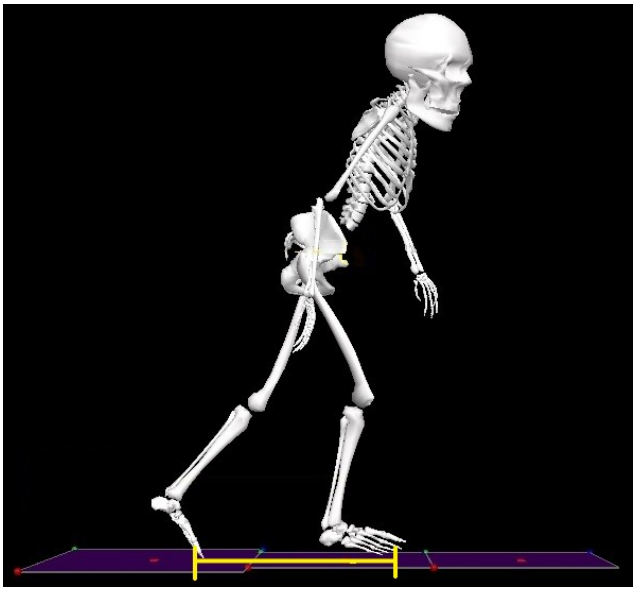


Figure 5.1 - Step Length (from start position to toe contact of first step)

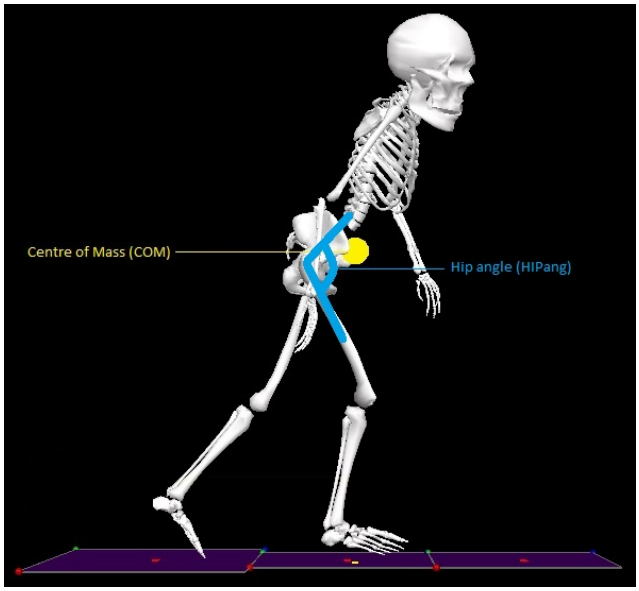


Figure 5.2 - Hip angle relative to the trunk

To address hypothesis one of this study; that higher pain in older adults with knee OA would be associated with unstable balance response, correlations were conducted between pain measures and the biomechanical measures. To address hypothesis two of this study; that lower executive function in older adults with knee OA would be related with unstable balance response, correlations were conducted between executive function measures and the biomechanical measures.

Correlations were interpreted via already published rule of thumb (Rosner, 2016; Schober, Boer, & Schwarte, 2018); ± .00 to .10 = negligible, ± .10 to .39 = weak, ± .40 to .69 = moderate positive/negative, ± .70 to .89 = strong positive/negative and ±.90 to 1.00 = very strong positive/negative. To avoid influence of spurious outliers, the interquartile range method was used (Laurikkala et al., 2000). Significance level was set at < .05.

In order to detect the difference in biomechanical measures between the PainDETECT types (Nociceptive, Unclear and Neuropathic), a chi square test was conducted. Analysis was carried out using SPSS 26 (IBM SPSS Statistics).

5.3 Results

5.3.1 Sample

As noted in Table 5.1, mean age was 73.38 years (± 6.36), mean height was 1.66 meters (± 0.10), mean body mass was 83.11 kilograms (± 16.42) and BMI was 30.07 (± 2.50). Of this sample, n = 14 (58%) were female.

Table 5.1 - Participant characteristics, and pain and executive function assessment scores (mean ± SD)

		Mean ± SD
AGE (Year)		73.38 ± 6.36
HEIGHT (m)		1.66 ± 0.10
Mass (kg)		83.11 ± 16.42
BMI (kg/m^2)		30.07 ± 2.50
FEMALES (%)		14 (58%)
Pain measures	BPI – Severe (max = 10)	1.99 ± 1.70
	BPI – Interference (max = 10)	1.70 ± 2.06
	FPQ – Minor (max = 50)	14.54 ± 3.75
	FPQ – Severe (max = 50)	26.79 ± 11.72
	FPQ – Medical (max = 50)	16.58 ± 3.95
	FPQ – Total (max = 150)	57.92 ± 15.45
	PCS – Rumination (max = 16)	3.79 ± 3.99
	PCS – Magnification (max = 12)	3.08 ± 3.81
	PCS – Helplessness (max = 24)	3.88 ± 3.93
	PCS – Total (max = 52)	10.75 ± 9.83
	WOMAC – Pain (max = 20)	5.63 ± 3.33
	WOMAC – Stiffness (max = 8)	2.71 ± 1.86
	WOMAC – ADL (max = 68)	17.58 ± 8.96
	WOMAC – Total (max = 96)	25.92 ± 13.30
Executive Function measures	TMT Total (s)	112.40 ± 36.19
	Stroop Dots (s)	14.72 ± 2.38
	Stroop Words (s)	26.75 ± 10.92
	Stroop Colours (s)	23.27 ± 3.04
	Stroop Interference (s)	8.55 ± 3.13
	Wechsler DST Total (max)	15.25 ± 3.03

BPI = Brief Pain Inventory – Short Form, FPQ = Fear of Pain Questionnaire, PCS = Pain Catastrophising Scale and WOMAC = Western Ontario and McMasters Universities Osteoarthritis Index, TMT = Trail Making Test, DST = Digit Span Test

5.3.2 Correlation between biomechanical response to perturbation and pain

Table 5.2 shows correlation between biomechanical responses and pain measures in this sample. There were no significant correlations noted between the selected biomechanical variables, other than (1) low pain interference weakly correlated with low angular velocity (Figure 5.3), (2) greater fear of minor pain negatively moderately correlated with lower hip flexion angle (Figure 5.4), (3) and greater fear of severe pain weakly correlated with increased hip flexion angle (Figure 8.5). Greater fear of severe pain was also moderately correlated with increased hip angular velocity (Figure 5.3), and higher overall fear of pain was correlated with increased hip angular velocity (Figure 5.4).

Table 5.2 - Correlation between biomechanical response and pain

		COM_{vel} (m/s)		**$STEP_{length}$ (m)**		**$STEP_{vel}$ (m/s)**		**HIP_{ang} (deg)**		**$HIP_{ang.vel}$ (m/s)**	
		r	***p***	***r***	***p***	***r***	***p***	***r***	***p***	***r***	***p***
BPI-SF	Severity	.32	.13	-.04	.85	.04	.87	.26	.21	-.01	.96
	Interference	.24	.27	-.31	.14	-.30	.16	.31	.14	.35	.89
FPQ	Minor	.17	.42	.18	.41	.23	.29	.29	.32.2	.09	.69
	Severe	.13	.56	-.16	.44	-.08	.71	.35	5	***.64***	***.02****
	Medical	-.06	.77	-.10	.63	-.13	.56	-.02	.06**	.19	.39
	Total	.12	.57	-.11	.61	-.04	.86	.19	.92	***.60***	***.03****
									.36		
PCS	Rumination	.01	.95	.20	.34	.22	.30	.13	.54	-.14	.53
	Magnification	.02	.92	.06	.78	.04	.85	.16	.46	-.30	.15
	Helplessness	.24	.26	-.14	.53	-.14	.52	.28	.19	-.03	.89
	Total	.11	.62	.05	.83	.05	.83	.21	.33	-.15	.47
WOMAC	Pain	.14	.53	.18	.41	.16	.45	.33	.27	-.14	.53
	Stiffness	.11	.60	.02	.94	.00	.99	.18	.56	.02	.92
	Activities of Daily Living	.16	.46	.16	.46	.11	.60	.27	.37	-.04	.85
	Total	.16	.47	.15	.48	.12	.59	.30	.32	-.06	.78

BPI-SF = Brief Pain Inventory – Short Form, FPQ = Fear of Pain Questionnaire, PCS = Pain Catastrophising Scale and WOMAC = Western Ontario and McMasters Universities Osteoarthritis Index, COM_{vel} = centre of mas velocity, $STEP_{length}$ = step length, $STEP_{vel}$ = step velocity HIP_{ang} = hip angle (flexion) and $HIP_{ang.vel}$ = hip angular velocity, **** significance at p <0.05, ** trend at p >.05 and <.10***

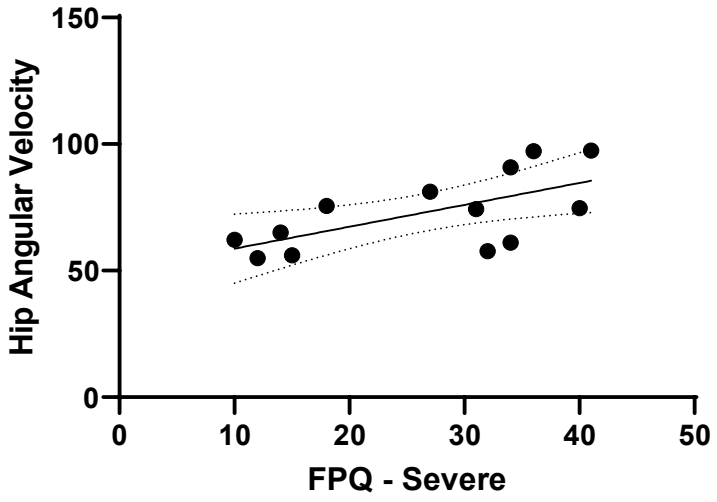


Figure 5.3 - Scatter plot for fear of severe pain (from FPQ) to hip angular velocity

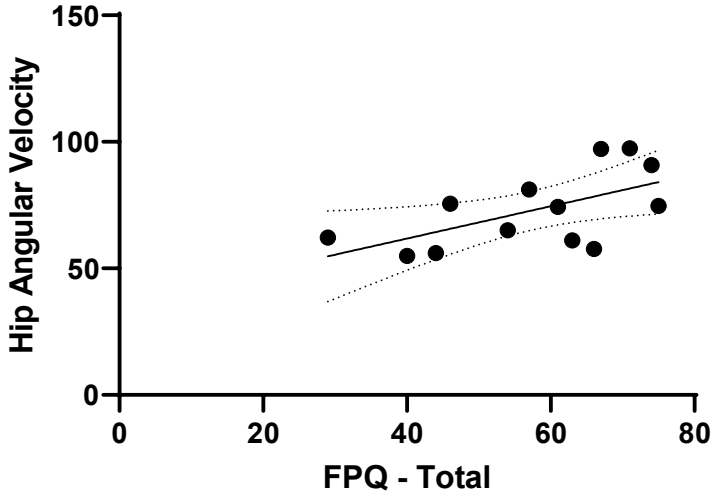


Figure 5.4 - Scatter plot for total fear of pain (from FPQ) to hip angular velocity

Table 5.3 shows biomechanical response characteristics for each of the PainDETECT types (Nociceptive, Neuropathic and Unclear). There was no significant difference between biomechanical variables.

Table 5.3 – Chi square analysis of PainDETECT Type by biomechanical responses

		COM_{vel} (m/s)		$STEP_{length}$ (m)		$STEP_{velocity}$ (m/s)		HIP_{angle} (deg)		$HIP_{ang.vel}$ (m/s)	
		χ^2	*P*	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*
PainDETECT		.61	.74	1.94	.38	1.30	.53	2.82	.25	.59	.75
Nociceptive (%)	17 (70.8%)										
Unclear (%)	5 (20.8%)										
Neuropathic (%)	2 (8.4%)										

COMvel = centre of mas velocity, STEPlength = step length, STEPvelocity = step velocity HIPangle = hip angle (flexion) and HIPang.vel = hip angular velocity and OA = osteoarthritis, **** significance at p <0.05, ** trend at p >.05 and <.10***

5.3.3 Correlation between biomechanical response to stability and executive function

Table 5.4 shows correlation between biomechanical responses and executive function measures in this sample. There were no significant correlations between any assessments of executive function, and the selected biomechanical measures.

Table 5.4 - Correlation between biomechanical response and executive function

		COM_{vel} (m/s)		$STEP_{length}$ (m)		$STEP_{velocity}$ (m/s)		HIP_{angle} (deg)		$HIP_{ang.vel}$ (m/s)	
		r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
TMT	Total	-.18	.40	.27	.20	.08	.71	.22	.30	-.07	.76
STROOP	Dots	.19	.38	.12	.58	-.07	.76	.22	.31	-.08	.71
	Words	.06	.80	.11	.82	-.01	.96	.13	.56	-.21	.33
	Colours	.05	.82	.14	.50	.14	.52	.22	.31	.08	.70
	Interference	-.07	.76	.08	.73	.16	.44	-.01	.97	.24	.27
WECHSLER	Total	-.02	.91	-.05	.83	.01	.96	-.04	.86	-.10	.65

TMT = Trail Making Test, STROOP = Stroop Colour and Word test, WECHSLER = Wechsler memory scale, COMvel = centre of mas velocity, STEPlength = step length, STEPvelocity = step velocity HIPangle = hip angle (flexion) and HIPang.vel = hip angular velocity and OA = osteoarthritis, **** significance at p <0.05, ** trend at p >.05 and <.10***

5.4 Discussion

5.4.1 Summary of main findings

Aim one of this study was to determine the influence of pain on biomechanical response to an induced fall in older adults with knee OA. With respect to this aim, there was correlation between pain and motion about the hip only (both flexion angle, and in angular velocity), but only in some pain assessments. In particular greater fear of severe pain correlated with increased hip angular velocity and also overall higher fear of pain was correlated with increased hip angular velocity.

Aim two of this study was to determine the influence of executive function on biomechanical response to an induced fall in older adults with knee OA. With respect to this aim, there was no correlation between any biomechanical and executive function measures.

5.4.2 Influence of pain on biomechanical response to an induced fall in older adults with knee OA

This present study reflects the ongoing debate about the effect of pain on stability in older adults with knee OA. The majority of results show no relationship to the biomechanical responses, identified in Chapter 4 of this thesis, as being common measures of difference between OA and controls (velocity of centre of mass, step length, step velocity, hip flexion angle and hip angular velocity). There was little variation in how participants rate either severity of pain, or how the pain interferes with life and nor was there any particular catastrophising of pain in this cohort. This suggests that any reported pain may have limited influence on their daily life, and that the sample had no major concern with respect to the presence of pain. Furthermore, the lack of correlation with respect to fear of medical pain may also support this argument suggesting that the current sample perceived discomfort from OA as minimal.

Pain has been linked to impaired balance in older adults (Hirase, Makizako, et al., 2020; Hirase, Okubo, et al., 2020), primarily via slower initiation of step response, and by taking of shorter and slower steps. As discussed in Chapter 2 of this thesis

(Section 2.2.3), the employment of two or more steps strategy during stability is an unstable response which is more likely to increase the risk of falling (Carty, Cronin, et al., 2012a; Carty et al., 2011). Meta-analyses have shown that those experiencing pain are twice as likely to fall as those who do not (Stubbs, Binnekade, et al., 2014a, 2014b), and while knee OA is linked to balance dysfunction, the connection between pain and falls in this population has, to date, shown inconsistent results (Manlapaz et al., 2019).

Relationships were found between (1) fear of severe pain, such as being in a car accident or breaking an arm ($r = .64$, $p = .02$) and (2) total fear of pain ($r = .60$, $p = .03$), and hip angular velocity. The speed at which the angle of the hip changes appears to be somewhat influenced by perception of pain. Where there is a fear of severe, and total pain, any changes to hip angle are done so more rapidly. The levels of pain reported, and the type of pain in this sample may, to a degree confound these outcomes. This was a homogenous sample showing little variation in any demographic measure, who mainly reported nociceptive pain, and had low to moderate pain scores across all measures. Further studies would also need to include all types of pain (nociceptive and neuropathic), including higher pain levels, and a more representative sample of the progression of OA.

5.4.3 Influence of executive function on biomechanical response

In this study there was no correlation between biomechanical variables, identified in Chapter 4 of this thesis (velocity of centre of mass, step length, step velocity, hip flexion angle and hip angular velocity), and measures of executive function.

The effect of executive function on stability appears to manifest itself in difficulties with balance including movement initiation, attention and adaptability when faced with challenges (Beauchet et al., 2009; Kearney, Harwood, Gladman, Lincoln, & Masud, 2013). While the discussion connecting stability and executive function is, relatively, novel there has been demonstrated links between walking and talking (Lundin-Olsson, Nyberg, & Gustafson, 1997; Yogev-Seligmann et al., 2008). In older adults with knee OA poor executive function scores were associated with poor physical function while walking (via assessment of gait speed and stair climb) but not

directly to falls (Morone et al., 2014). While there is some evidence demonstrating an association between executive function and falls, the mechanisms of this relationship has not yet been demonstrated (Kearney et al., 2013).

There may be two primary explanations for the lack of correlation within this study, first is the homogenous sample included in this project which shows little variation between participant responses. Second is the performance of the group in this study, on all executive function measures which appear similar to that of normative data. While these findings might appear to contradict established connection between age related cognitive decline and poor balance (Hawkes, Siu, Silsupadol, & Woollacott, 2012) it is important to note that, to date, most studies in this area focus on falls during gait. Further to this is the general acknowledgement that gait is a far more cognitively complex task than balance alone and are exacerbated by poorer executive function (Hawkes et al., 2012).

5.5 Conclusion

The connection between pain and stability in OA is variable, particularly where low pain scores are reported. In relation to executive function there is also a lack of clarity where performance is comparable to asymptomatic older adults.

In this study, there was little variation in rate of pain severity, a further lack of difference in relation to the interference of that pain, and there was no noted catastrophising of the pain. How the pain influences on stability in older adults with knee OA is in relation to motion of the hip is unclear. Perhaps the lack of hip flexion noted in this study is more reflective of poor strength in older adults with knee OA when compared to asymptomatic controls. The executive function measures showed no correlation with any biomechanical measure analysed, presumably arising from the homogenous sample with results within normal range.

Chapter 6 – Predicting falls in older adults with Knee Osteoarthritis

Abstract

To date, limited studies have prospectively investigated falls in older adults. The main foci of these studies being on the prediction of falls arising from symptoms related to OA including pain and stiffness as well as other factors surrounding OA such as previous falls, overall health, and physical activity. This chapter employs a prospective cohort design to determine if the identified biomechanical measures during stability and other recorded data can be used to predict future falls. Outcomes of this study suggest that there is potential for prediction of female fallers using biomechanical measures such as high velocity of centre of mass and reduced knee flexion.

6.1 Introduction

There is increased likelihood of falling in people with knee OA, including a 25% increase in women (Prieto-Alhambra et al., 2013), for 2.6 years post data collection where pain is higher, and stiffness greater (Scott, Blizzard, Fell, & Jones, 2012). Furthermore, history of falling, poor overall health and low amounts of physical activity are also predictors of falls in total knee replacement participants (Levinger, Wee, et al., 2017). While these studies have investigated falls prediction, they did not address biomechanical variables which might predict falls in an OA population.

As discussed throughout this thesis, in otherwise healthy older adults, shorter and slower steps are linked to the taking of multiple steps following perturbation and are therefore linked to falls (Barrett et al., 2012; Carty, Cronin, et al., 2012a; Carty et al., 2015; Carty et al., 2011; Maki & McIlroy, 1997, 1998). From Chapter 4 of this thesis, there were certain biomechanical measures which relate to unstable stability following perturbation in older adults with knee OA when compared to controls. These included variables common to studies involving healthy older adults such as: shorter step length at lower velocity. Other biomechanical measures identified that

are not common with research into healthy older adults included lower velocity of centre of mass, lower hip flexion angle and slower hip angular velocity. Also, knee specific variables such as knee angle, moment, and angular velocity, which, while identified as contributing to joint instability in knee OA (Levinger, Nagano, et al., 2016b; Yakhdani et al., 2010), have also not been investigated as predictive for falls in this population.

While there is an acknowledged falls risk in older adults with knee OA, arising from both the disease itself and from complications surrounding the disease, there has been no studies, to date, to identify which biomechanical measures during falls from induced leans might predict future falls in older adults with knee OA. Therefore, the aim of this study was to identify the biomechanical measures during stability associated with falling as predictors for falls in older adults with knee OA.

6.2 Methods

A logistic regression model was fitted using falls data and their corresponding biomechanical and other data such as medication and patient demographics. The study protocol was approved by the Victoria University Human Research Ethics Committee (HRE16-065), and all participants were information about the details of the study and signed a consent form before participating.

6.2.1 Study design

A prospective cohort study design was employed with 12 months follow up to predict falls in sub-group of older adults with knee OA.

6.2.1 Participants

From the Knee OA group in Chapter 4 of this thesis, twenty-four participants were selected for this study. This sample was chosen due to both community dwelling status, and also willingness to participate in a yearlong study. Inclusion criteria included age between 60 and 90 years old, self-ambulatory, community dwelling and without neurological and neurocognitive deficit. All study participants met the National Institute for Health and Care Excellence guidelines CG177 (NICE, 2014) for diagnosis of OA.

6.2.2 Data collection

Data collection relating to participants' performance during stability was carried out as described in Chapter 3 – Methodology, section 3.6 Procedure. Following collection of data on demographics, medical history and biomechanics, participants completed 12 months of falls calendars.

6.2.2.1 Demographics and medical history

During initial assessment, prior to biomechanical data collection but following assessment for cognitive inclusion (SLUMS test, Chapter 2, 2.8.1 Cognitive test for study inclusion), participants were interviewed regarding medical conditions present including cardiovascular conditions, hypertension, stroke, high cholesterol, diabetes, respiratory conditions or other not listed condition. Further detail was also sought regarding musculoskeletal injury, other than knee OA. Lastly medications were also recorded, including type and number of doses.

6.2.2.2 Falls surveillance

Participants were provided with 12 months of pre-printed falls calendars (Appendix 14) along with pre-paid envelopes and were instructed to return at the end of each month. If there was a fall recorded, the participant was instructed to call the researcher (on a provided phone number included on the calendar) so that the details and circumstances of the fall could be discussed. The fall was also to be noted on the calendar. Falls were defined using the World Health Organisation definition of “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” (WHO, 2007)

During the phone discussion, participants were asked to describe the fall to determine if it was an actual fall, or near fall, location of the fall (at home, or away from home), what was happening at the time of the fall (housework at home, gardening at home, unspecified activity at home, or away from home) and the cause of the fall (lost balance, trip/slip, faint/unwell or unsure). If there was no fall in the month, the sheet was to be returned with a check in a box labelled “I had no falls this month”.

6.2.3 Falls Prediction Model Development

Participants were classified as fallers (one or more falls) or non-fallers based on returned prospective falls calendars during the 12 months post data collection.

From initial data collection, all biomechanical measures investigated in Chapter 4 were compared between fallers and non-fallers using *t* tests in SPSS. Variables with a significance level of $p \leq 0.1$ (variables showing at least trend) were retained for the prediction model, as per previous studies (Levinger, Wee, et al., 2017). Seven variables were identified: velocity of centre of mass, knee angle, knee moment, knee angular velocity, gender, number of medications and comorbidities. To create the prediction, a logistic regression model was fitted using the glm() function in R (R Core Team, 2021) using the variables with significance levels of $p \leq 0.1$. The model provides an estimate, *p*, or the probability of being in the falls group and is given by:

$$\log\left(\frac{p}{(1-p)}\right) = \beta_0 + \beta_1 \times \ centre\ of\ mass\ velocity + \beta_2 \times \ knee\ angle + \beta_3 \times \ knee\ moment + \beta_4 \ \times \ knee\ angular\ velocity + \beta_5 \times \ gender + \beta_6 \times \ number\ of\ medications + \beta_7 \ \times \ comorbidities$$

Where β_0 is the intercept and β_n (n=1-7) are the coefficients.

To allow the coefficients to be compared, following Gelman, Hill & Vehtari (2021), the gender variable was coded -0.5 for females and 0.5 for males, while the other variables were centred by subtracting their mean and scaled by dividing by twice their standard deviation.

Receiver Operating Characteristic (ROC) analysis (Hosmer et al., 2013) was conducted, in R, using the selected variables to predict selection in the model. An ROC curve (Figure 6.1) is a graphical plot illustrating ability to diagnose a binary system (two groups) using cut-off points for a variable. Within the curve, the true positive (sensitivity) is plotted against the false positive (specificity). Area under the curve values, from Hosmer et al (2013) Chapter 5, were set as:

- ROC = 0.5 no discrimination,
- 0.5 > ROC < 0.7 poor discrimination,
- 0.7 ≥ ROC < 0.8 acceptable discrimination,
- 0.8 ≥ ROC < 0.9 excellent discrimination, and

- ROC ≥ 0.9 outstanding discrimination.

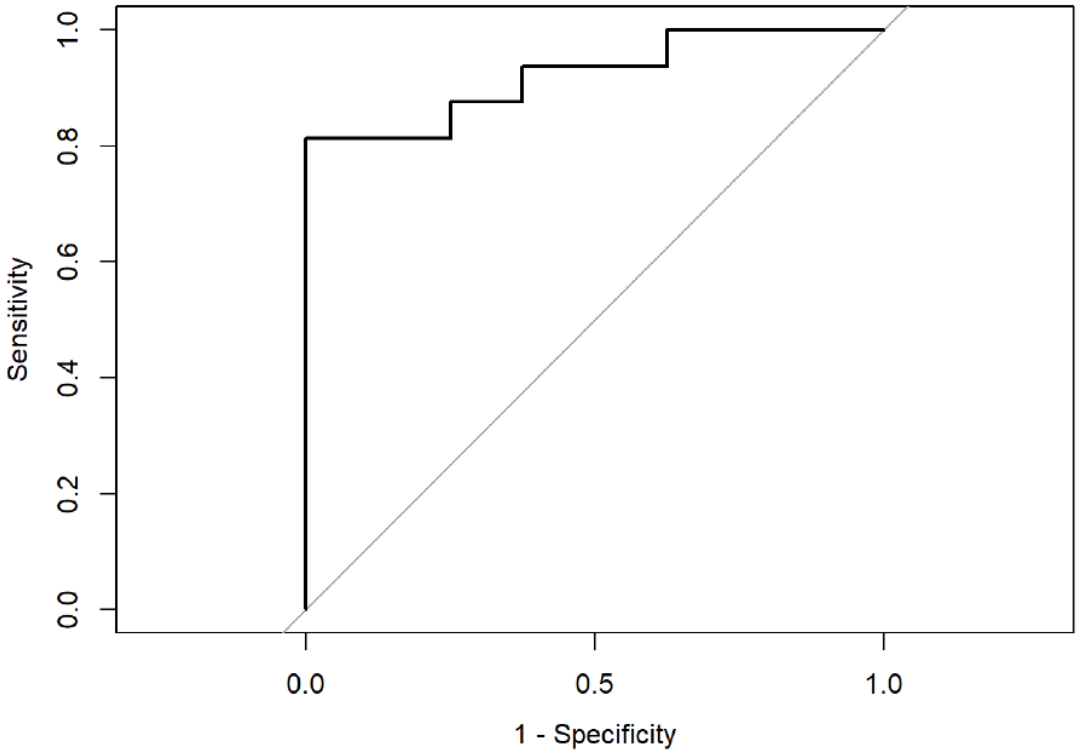


Figure 6.1 - An example ROC curve showing relationship between Sensitivity and Specificity

To assess accuracy of the predicted model, Leave One Out Cross Validation (LOOCV) was carried out. This was carried out via excluding each data point in turn and predicting it based on the logistic regression model developed on the rest of the data.

Finally, analysis of deviance (Hastie & Pregibon, 1992) was conducted to measure the difference between the best fit additive model and the predictive model.

6.3 Results

6.3.1 Falls during surveillance period

Table 6.1 shows falls incidents and associated circumstances surrounding the falls. In total 126 incidents were reported over the follow-up period, and following review with the researcher, 66 (52.4%) of these incidents were re-classified as near falls. That is, the participant was able to recover via means such as reaching out to walls, furniture, handrails, or other people thus avoiding an actual fall as defined by the WHO (2007). Therefore 60 (47.6%) actual falls were assessed. There were 16 fallers classified, and 81.3% of these subjects fell more than once, with a mean of 3.75 falls per faller in the surveillance period.

The majority (83.3%) of falls occurred at home, with the activity of the time of the fall mainly being either housework or gardening (each with 38% occurrence). The most common cause of a fall was lost of balance (60%).

Table 6.1 - Incidence of falls and near falls, by reported location, activity, and cause

Incidents reported	**n (%)**
Near fall	66 (52.4%)
Actual fall	60 (47.6%)
Total falls	*126 (100%)*
Falls during surveillance period	
Mean number of falls (95% CI)	3.75 ± 2.35 (2.50, 5.00)
Number of fallers	16 (66.7%)
Subjects with more than 1 fall	13 (81.3%)
Breakdown of actual falls data	
Fall location	
At home	50 (83.3%)
Away from home	10 (16.7%)
Activity when fall occurred	
Home – Housework	19 (31.7%)
Home - Gardening	19 (31.7%)
Home – Not specified	12 (20%)
Away – Not specified	10 (16.7%)
Cause of fall	
Lost balance	36 (60%)
Trip/Slip	9 (15%)
Faint/Unwell	5 (8.3%)
Unsure	10 (16.7%)

Table 6.2 shows step response characteristics for each of the non-faller and faller groups (classified based on the follow-up period). There was no significant difference between step responses (single vs multiple steppers) and groups, χ^2 (2, N = 24) =.38, p = .54).

Table 6.2 - Step responses, by group classification (based on follow-up period)

	Non-Faller (n = 8)	**Faller (n = 16)**	**χ^2**	***p***
Single step (%)	2 (25%)	6 (37.5%)	.38	.54
Multiple step (%)	6 (75%)	10 (62.5%)		

**** significance at p <0.05***

6.3.2 Sample demographics and medical history

As noted in Table 6.3, no differences were reported in age, height, mass, BMI nor gender between the groups (faller and non-faller) ($p > .05$).

With respect to medications, overall, there was no difference in total usage, nor drug types, between groups.

Finally, there was no difference in presented co-morbidities between the groups ($p = 1.00$). .

Table 6.3 - Participant characteristics grouped by falls in follow up (mean ± SD reported)

	Non-Faller (n = 8)		Faller (n = 16)		
	Mean ± SD	**95% CI**	**Mean ± SD**	**95% CI**	***p***
AGE (Year)	72.75 ± 9.00	65.56, 80.24	73.69 ± 5.19	70.92, 76.45	.75
HEIGHT (m)	1.68 ± 0.08	1.62, 1.75	1.65 ± 0.11	1.59, 1.71	.39
Mass (kg)	83.51 ± 15.69	70.40, 96.63	82.91 ± 17.79	73.44, 92.40	.94
BMI (kg/m^2)	29.45 ± 5.27	25.04, 33.86	30.37 ± 4.38	28.04, 33.86	.65
FEMALES (%)	3 (37.5%)	-	5 (31.3%)	-	.14
MEDICATIONS					
Anti-hypertensive (%)	8 (100%)	-	9 (56%)	-	.22
Cholesterol lowering (%)	5 (63%)	-	7 (44%)	-	1.00
Blood thinner (%)	2 (25%)	-	7 (44%)	-	.39
Pain relieving (%)	2 (25%)	-	6 (38%)	-	.14
Respiratory relieving (%)	-	-	-	-	-
Glucose lowering (%)	-	-	-	-	-
Anti-depressive (%)	1 (13%)	-	2 (13%)	-	.62
Total medications	*3.88 ± 2.32*	*2.01, 5.74*	*4.06 ± 2.08*	*2.95, 5.17*	*.84*
CO-MORBIDITIES					
Hypertension (%)	8 (100%)	-	9 (56%)		.22
Hypercholesterolaemia (%)	5 (63%)	-	7 (44%)		1.00
Respiratory conditions (%)	-	-	-		-
Cardiovascular conditions (%)	2 (25%)	-	7 (44%)		1.00
Metabolic disorders (%)	-	-	-		-
Osteopenia (%)	1 (13%)	-	1 (13%)		.32
Diabetes Mellitus (%)	-	-	-		-
Total co-morbidities	*1.63 ± 1.19*	*0.63, 2.62*	*1.63 ± 1.15*	*1.04, 2.24*	*1.00*

BMI = Body Mass Index, **** significance at p <0.05, ** trend at p >.05 and <.10***

6.3.3 Predicting falls in older adults with knee OA

6.3.3.1 Variables retained for Model development and ROC analysis

Table 6.4 shows the results of t-tests carried out on all key biomechanical measures related to stability performance and identified in Chapter 4 of this thesis, alongside knee specific measures identified as contributing to joint instability in knee OA (Levinger, Nagano, et al., 2016b; Yakhdani et al., 2010). Only significant measures were retained for regression analysis in this present study.

*Table 6.4 - Measures for prospective t-tests, * variables retained for regression analysis*

Type	***Measure***	***T-test p***
Spatio-temporal	step length	.85
	step velocity	.48
Kinematic and Kinetic	***velocity of centre of mass***	***.03****
	hip angle	.24
	hip angular velocity	.97
	knee power absorption	.68
	knee angle	***.10***
	knee moment	***.07***
	knee angular velocity	***.06***

The seven identified variables (velocity of centre of mass, knee angle, knee moment, knee angular velocity, gender, number of medications and comorbidities) were used to develop the prediction model. This provided altogether 128 additive models, allowing the inclusion or exclusion of various combination of the seven variables. The performance of the models were evaluated using ROC analysis and LOOCV. The full analysis results are provided in Appendix 15. Analysis of deviance (Table 6.5) shows significance of the variables chosen for the best fit additive model: velocity of centre of mass (p = .04), knee moment (p = .03) and gender (p =.02).

Table 6.5 - Analysis of Deviance for best fit additive model

	Likelihood ratio Chi2	**Degrees of freedom**	***p***
Velocity of centre of mass	***4.15***	***1***	***.04****
Knee angle	0.06	1	.81
Knee moment	***4.54***	***1***	***.03****
Knee angular velocity	0.01	1	.94
Gender	***5.35***	***1***	***.02****
Number of medications	0.24	1	.61
Comorbidities	1.77	1	.18

**** significance at p <0.05, ** trend at p >.05 and <.10***

When considering the identified biomechanical and categorical variables, the best fit additive model, in terms of LOOCV, was a model that included high velocity of centre of mass, negative knee moment, and female gender. Of the top 10 models included in the analysis (see Appendix 15), in terms of LOOCV, eight included velocity of centre of mass, nine included knee moment and all 10 included gender.

The model selected included an area under the curve value of 0.6562 (Figure 6.2) and explains 21.1% of the deviance. The proportion explained by each variable is (note – the sum of the three exceeds 21.1% because of the correlation between the variables):

- Velocity of centre of mass 10.7%,
- Knee moment 11.2%, and
- Gender 11.4%

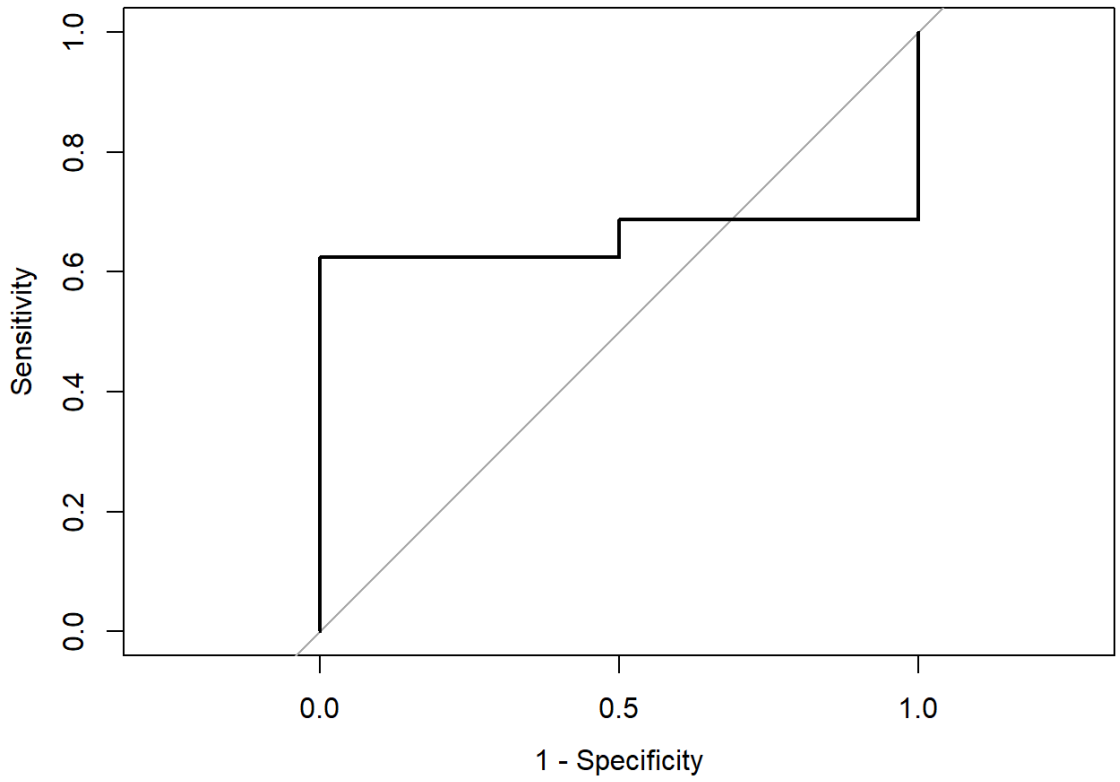


Figure 6.2 - ROC curve (ROC area 0.6562) for best additive model to predict falls

For overall gender, predicted probability of falling based on velocity of centre of mass (Figure 6.3) is similarly low at low velocities, and is high at higher velocity. Any gender-based difference appears to be that, in women, probability of falling increases sharply from comparatively low velocities. In men, however, probability of falling increases with higher velocity. Predicted probability of falling based on knee moment (Figure 6.4) is similarly high where the knee is in extension (negative

moment values) and is a less likely where the knee is in flexion (positive moment values). Any gender-based difference appears to be that, in women, probability of falling is higher into low knee flexion moment (just above 0.0) whereas for male, probability of falling begins to lower much earlier. Overall Knee moment seems to have a higher influence on falls prediction in females.

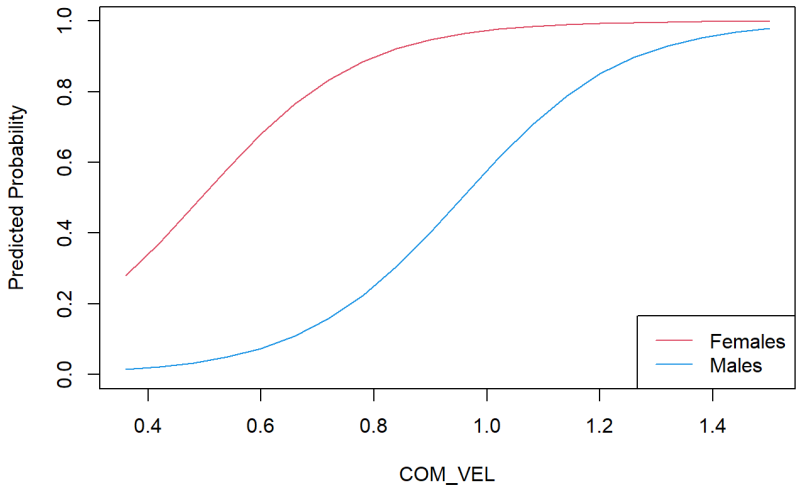


Figure 6.3 - predicted probability as a function of Velocity of centre of mass (COM_VEL), higher line represents females

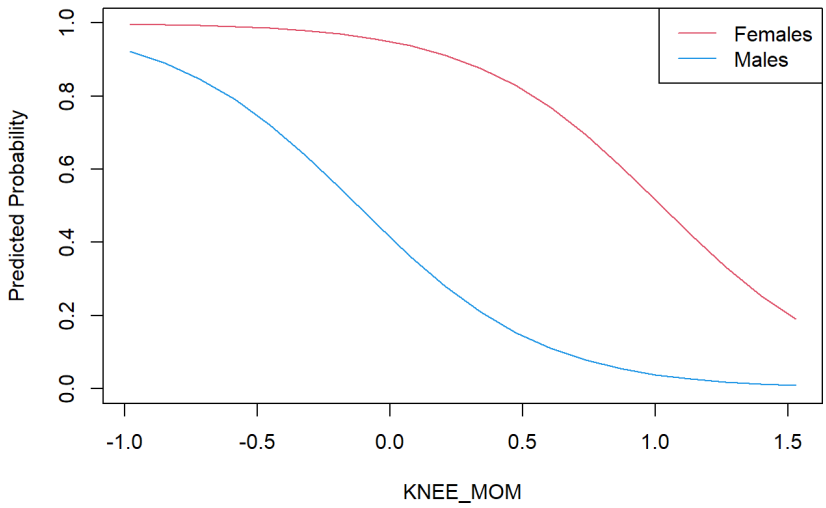


Figure 6.4 - Predicted probability of falling as a function of Knee Moment (KNEE_MOM), higher line represents females

Contour plots of predicted probability of a fall, assuming the best model, for both genders are given below.

For females (figure 6.5), of the 14 data points charted, 10 were from falls (in red) with 80% (8) of these showing excellent or outstanding discrimination (≥ 0.8 and ≥ 0.9 respectively) where velocity of centre of mass was high (approximately 0.8m/s and above) and with a greater tendency towards negative knee moment (closer to 0.0 and below, where the knee is in extension). Contour plots for male participants are illustrated in fig 6.6 and show relatively low discrimination probability compared to female participants.

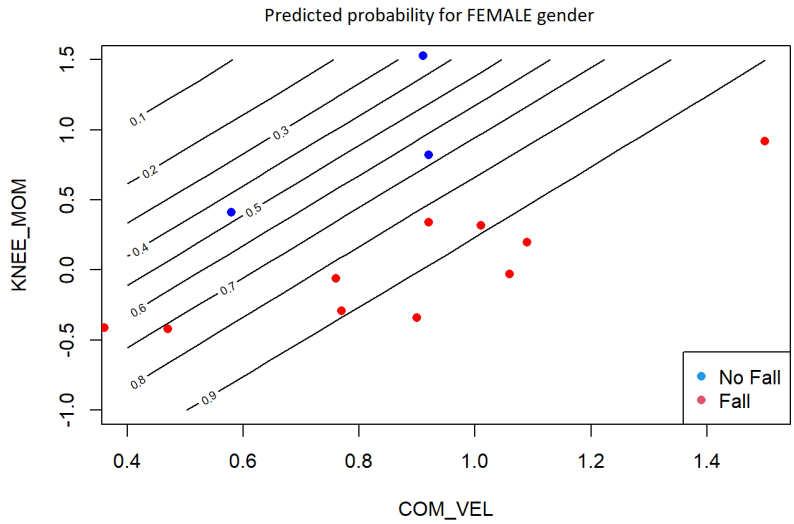


Figure 6.5 - Contour plot of predicted probability of a fall for females, assuming the best additive model

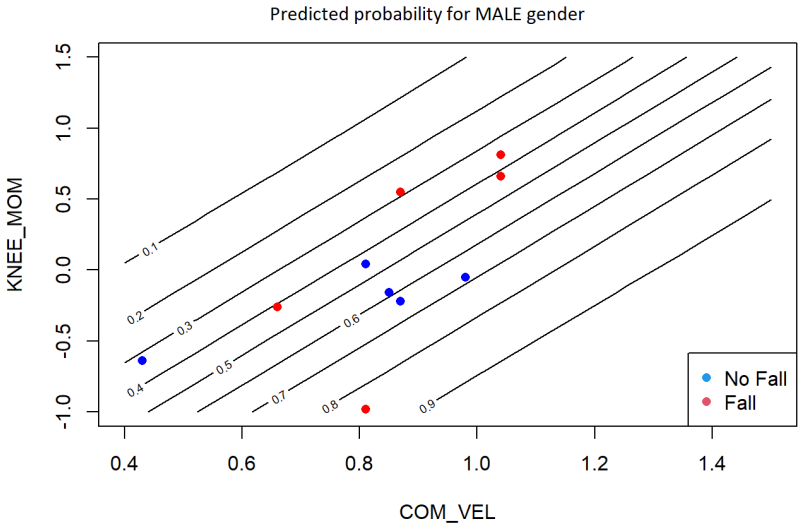


Figure 6.6 - Contour plot of predicted probability of a fall for males, assuming the best additive model

6.4 Discussion

6.4.1 Summary of main findings

The most important finding of this study is that a number of measures have been identified as potential predictors for falls in older adults with knee OA. These include nigher velocity of centre of mass, higher negative (extension) knee moment, and female gender.

The falls prediction model outlined in this chapter suggests both velocity of centre of mass and knee extension moment during stability tasks are related to fallers, but the influence is more pronounced in the females.

6.4.2 Participants and medical history

While the differences in the gender were not significant, it is perhaps an interesting observation as it may suggest that the falls rates in this study might be expected to be lower than is seen in published literature. Women are more likely than men to have OA (Silverwood et al., 2015), and are also more likely to fall (Painter & Elliott, 2009). In this study, however there were fewer females 33% (8) than men. As noted in the following section, however, falls rate during the surveillance period in this study is slightly higher. There is no identified reason for this arising from this study, as there is no difference in demographics between the two groups.

In relation to medical history, there is an overall lack of difference in both medication use and comorbidity in this sample. Given that high medication use, including type and number has been linked to increased falls risk (Hartikainen, Lönnroos, & Louhivuori, 2007), medication usage was included as one of the potential models during LOOCV processing (#6, appendix 15). Further analysis indicated a low likelihood of deviance from the model ($\chi^2 = 0.24$) and therefore medication usage was not included for further analysis. Similarly, comorbidities were omitted from the best additive model, also arising from the low deviance ($\chi^2 = 1.77$).

6.4.3 Falls during surveillance period

In this present study there were, in total, 16 fallers in the follow up period which represents 66.7% of the sample. This is similar, though slightly higher, to the rates of falls reported for people with knee OA ranging from 40-64% (Dore et al., 2015). This suggests that the number of falls in this follow up period is approximately that of other studies reported in this area.

While most falls happened at home (83.3%), there is equal distribution of whether the falls were in, or outside, the dwelling. This is in contrast with Levinger et al (2017) where it was noted that most falls were outside. Furthermore, the most likely cause of a fall in the present study was 'loss of balance' as opposed to trips and slips (Levinger, Wee, et al., 2017). There may be a number of reasons for this discrepancy, including different populations (Levinger used total knee replacement patients), and difference in reporting and perception of both participants and the researcher in the present study.

Finally, the step response (single v multiple) shows no statistical difference between groups in relation to the steps taken for stability. However, it is nonetheless notable that a higher proportion of non-fallers (75%) employed a multiple step response following perturbation than did fallers (62.5%). While there is no answer to this finding in this study, it is an observation perhaps worthy of further study.

6.4.4 Prediction of falls

In this chapter a logistic regression model was fitted using falls data and their corresponding biomechanical measures, medication, and patient demographics. The model is based on a relatively small sample (n=24), and is therefore preliminary, but it shows a technique for falls prediction using biomechanical and other relevant data. The model indicates that there are some biomechanical data that are important in future falls prediction. An important observation was that falls prediction was gender-specific.

The very high discrimination in female subjects is demonstrated via the combination of both high velocity of centre of mass and knee moment which is either 0.0 or in the negative. Moments of these values reflect extension in the measured joint. Essentially, an extended knee is less capable of accepting forces associated with landing and when this is coupled with higher velocity of centre of mass the implication is poor control of the anterior motion of the body. This is far less clear cut with male subjects where there is no definitive pattern noted within the model. However, where female participants appeared less capable of controlling anterior motion of the body (approximate velocity of centre of mass of +0.8m/s, and knee moment approaching 0.0 and below) the male participants were less likely to fall. In fact, in this combination of velocity of centre of mass and negative knee moment, the only faller in the male group is the most negative moment data point. This may suggest that males are more likely to be able to accommodate higher velocity of centre of mass on an extended knee.

The reasons for a gender-based influence on likelihood of falls in OA have much supporting evidence. Women are more likely to experience OA (Manlapaz et al., 2019; Rudolph, Schmitt, & Lewek, 2007; Sandell, 2012). Women also have a higher prevalence of falls in the presence of knee pain (Dore et al., 2015; Muraki et al., 2011; Ofori-Asenso, Ackerman, & Soh, 2020), as well asymptomatically (Li, Gamber, Han, Sun, & Yu, 2020; Peeters, van Schoor, Cooper, Tooth, & Kenny, 2018). And there is a possibly related reduction in physical activity noted in older women (Ylitalo, Karvonen-Gutierrez, Sternfeld, & Pettee Gabriel, 2021), a known factor of increased falls risk (Thibaud et al., 2012).

6.5 Conclusion

This study is the first of its type with the aim of predicting falls in older adults from biomechanical and other measures with knee OA. While preliminary, the results show that a combination of high velocity of centre of mass and negative (extension) knee moment during stability tasks are two key biomechanical variables that may be used to predict future falls. The relationship between these two variables and the probability of future falls is much stronger in females than males. The sample size used in this prediction model however affords sensitivity of 0.2 with 95% confidence so a larger sample would be needed to reach higher probability in future models.

Chapter 7 – General Discussion and Recommendations

Falls in older adults are a major public health concern globally and, furthermore, are a major personal challenge for the individual with a history of, or is at risk of, falls. OA is a prominent disease which places those with the disease at increased risk of falling. While the lower limb has been investigated in an attempt to explain poor stability and increased falls risk, kinematics of the whole body has not. Distraction, obstacle clearance, pain and executive function all appear to have some level of influence on stability performance, but it is not clear to what level. Thus, the overall aims of this thesis were as follows:

1. to investigate instability, via whole body kinematics, of older adults with knee OA,
2. to investigate the relationship between pain and executive function, and biomechanical measures of instability in older adults with knee OA, and
3. to investigate the potential of using biomechanical measures to predict falls in older adults with knee OA.

7.1 General discussion

The overall outcome of this thesis was that older adults with knee OA were no more likely as controls to employ a multiple-step response following perturbation, reflecting similar stability in this group when compared to asymptomatic older adults. However, certain measures were noted in the OA group throughout this thesis that were significantly different than that of the asymptomatic controls, and which might make those with OA at a greater risk of instability following perturbation. These include both biomechanical (upper and lower body kinetics and kinematics) and pain measures.

7.1.1 Biomechanical factors in stability

Step response, either single or multiple, was suggested by Carty (2011) as a consequence of age and is the loss of ability to employ a single step strategy following perturbation. This occurs ostensibly through a combination of lower margin of stability as well as lack of knee flexion, both during landing phase of the recovery limb. In short, when compared to younger adults, older adults demonstrate poor control of the motion of the centre of mass, and less ability to absorb landing forces. This deficit requires activity in both the upper and lower body to arrest anterior motion when the perturbation results in forwards direction of travel. The summation of the biomechanical measures in this thesis seems to present a picture of instability in older adults with knee OA that is not reflected in the step response (single v multiple) in the accumulated studies presented. This suggests activity of other body segments is required to counteract the poor activity of the lower limbs.

The positioning of two-thirds of body mass at two-thirds of standing height (Haddad et al., 2013) results in an inverted pendulum whereby most motion occurs proximally in quiet stance (Winter, 1995). This pendulum effect is exacerbated in motion and where the trunk is flexed resulting in the mass of the head, arms and torso approaching (or exceeding) the boundary of the base of support. Where there is net anterior angular momentum of the trunk, there is a greater deleterious effect on

control of overall stability. While one might expect the trunk flexion to be more pronounced in older adults with knee OA it was, in this thesis, no different to that of the asymptomatic controls. In research comparing older and younger adults, greater trunk flexion angles were noted in the former group (Carty et al., 2011; Hsiao-Wecksler & Robinovitch, 2007; Karamanidis et al., 2008; Luchies et al., 1994; Madigan & Lloyd, 2005a, 2005b; Thelen et al., 2000; Thelen et al., 1997; Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander, 2001). Such a position has been postulated as age-related decline in strength or latency of hip extensors and/or erector spinae group of muscles (Hwang, Lee, Park, & Kwon, 2008), leading to lack of ability to maintain a more upright torso posture. However, research into age-related decline in biomechanical response to perturbation in older adults with knee OA has, until now, not included measures of the trunk making the assessment of Hwang et al not possible in this population. As this thesis has noted no difference in trunk flexion angle between OA and asymptomatic controls, it would appear that trunk positioning in older adults with knee OA has no deleterious effect on stability in this population. Any noted reduction in stability in the OA group is therefore, in all likelihood, a result of activity in the lower limb.

The employment of a strategy involving both shorter and slower steps has been well discussed in both asymptomatic older adults (Carty, Barrett, et al., 2012; Carty, Cronin, et al., 2012a, 2012b; Carty et al., 2015; Carty et al., 2011), and in older adults with knee OA (Downie, 2014; Levinger, Nagano, et al., 2016a; Levinger, Nagano, et al., 2016b). Such a strategy leads to instability via the taking of multiple steps following perturbation, a noted risk factor for falls (Carty et al., 2015). As discussed at length throughout this thesis, the data presented herein reflects the literature insofar as OA participants uniformly took shorter and slower steps regardless of trial condition. The result of this strategy was both lesser margin of stability (MOS) and reduced available response time (ART). While neither MOS nor ART were significantly different in this thesis, both variables were uniformly lower in the OA group than in controls suggesting a potential lack of stability. Carty (2015) identified poor margin of stability, in particular, as a measure of instability in older compared to younger adults. The lower margin of stability was, in turn, attributable to a number of factors not least of which was poor extension of the base of support. Briefly, short steps lead to a low margin of stability as the centre of mass position is

close to the anterior boundary of the base of support. Carty (2015) also identified lower peak knee flexion angle during the landing phase, further reflecting poor control of centre of mass motion in older adults. Older adults with knee OA have been shown as having difficulty in slowing momentum of the centre of mass via reduced joint angles and powers, particularly in dual-task scenarios (Levinger, Nagano, et al., 2016a). The studies in this thesis further support these arguments, via lower hip flexion angle and slower hip angular velocity across trial conditions, and lower knee power absorption when distracted. This is exacerbated during obstacle crossing where at the point of obstacle crossing the trajectory of the toe is closer to the obstacle compared to controls along with greater knee extension. The combined effects of these variables is not only greater risk of contact with the obstacle during crossing, therefore tripping, but also the placement of the recovery foot closer to the obstacle on landing, therefore having a shorter step and poor extension of the base of support. It appears that the presence of knee OA leads to posture of the lower limb incompatible with stability via poorer spatio-temporal, kinetic and kinematic measures. Particularly so in dual-task scenarios where distraction appears to negatively affect both knee and trunk kinematics, and where crossing an obstacle appears to have a deleterious effect on kinematics of the toe, ankle, knee, and hip.

7.1.2 Pain factors in stability

Pain is linked to poor balance outcomes in older adults through a variety of mechanisms including slow step response, and shorter and slower steps (Hirase, Makizako, et al., 2020; Hirase, Okubo, et al., 2020), and increases the risk of falls (Stubbs, Binnekade, et al., 2014a, 2014b). In older adults with knee OA, while there is a demonstrated negative effect on balance and increased falls risk, there are conflicting views on any similar effect from pain in this population (Manlapaz, Sole, Jayakaran, & Chapple, 2019). Meta-analysis has shown that, while pain is a symptom of OA (Hunter, McDougall, & Keefe, 2008), and pain is associated with a decline in static balance (Jadelis, Miller, Ettinger Jr., & Messier, 2001; Messier, Glasser, Ettinger Jr., Craven, & Miller, 2002) there has been no definite association between pain and dynamic balance in this population (Levinger, Downie, et al.,

2016). While Levinger et al (2016) noted a lack of significant difference in pain levels in step responses (single v multiple), increased risk of falls only occurs when the pain is severe or chronic (Stubbs, Binnekade, et al., 2014a).

This thesis reflects the the debate in the literature, in particular the connection between pain and stability in older adults with knee OA. Specifically, there was no correlation between any pain measure and velocity of centre of mass, step length and step time. Only moderate correlations (in either direction) existed between hip angle and fear of pain (minor and medical) and OA related pain, stiffness and activities of daily living. Furthermore, only moderate postitive correlations are present between hip angular velocity and interference from pain, and fear of severe pain.

While the levels of pain reported in this thesis are only mild, older adults with knee OA would appear to have little concern with respect to minor or medical pain. As might be expected with mild pain, there is no noted interference or catastrophising of pain. This again reflects the literature insofar as the presence of underlying chronic, aching pain is less impactful on quality of like than sharp and acute pain (Hawker et al., 2008). By contrast, in this thesis severe pain and osteoarthric pain do appear to have a relationship with the angle, and angular velocity of the hip. Specifically that higher pain scores correlate with lower hip flexion and slower hip angular velocity. Where the pain is related to OA specifically, or where the pain is unusually severe, the biomechanical response from older adults with knee OA is maintenance of an extended, and slow moving, hip joint. This could be interpreted as an attempt to subvert painful positioning of the joint and, as a consequence, tends to lead to a more stable position following perturbation..

It should be noted that this was a convenience sample taken from the overall sample from Chapter 4of this thesis, and while the preliminary data suggests that pain has little connection with stability other than some measures with motion of the hip, a larger sample may well yield different results. Furthermore, the sample is highly homogenous and as such is not necessarily representatitve of the broader OA population. While these results reflect this sample, a more representative cohost may well provide different outcomes.

7.1.3 Cognitive factors in stability

The connection between cognitive performance and stability appears centred upon starting movement, focus on the movement and changing the movement in the face of a challenge (Beauchet et al., 2009; Kearney et al., 2013). There are noted links between poor executive function and gait, in particular reduced speed, (Lundin-Olsson et al., 1997; Yogev-Seligmann et al., 2008) but prior to this thesis, no investigation into any relationship between executive function and balance in older adults with knee OA has been conducted. While there was no relationship identified between executive function and balance in this thesis, there are two points of discussion. First relates to the sample, and second relates to the effect of pain on cognition.

With respect to the sample, in this thesis it was not only homogenous with very little difference in participant response to executive function testing, but it was also a sample which scored highly on testing. Compared to age-matched norms, participants in this study scored higher in areas related to both task switching (faster) and reaction time (reduced). The homogenous results of the executive function in the OA group may possibly skew the results and suggest that there was no relationship between executive function and biomechanical measures. Further studies, with broader performance in cognitive testing may well expose a relationship not yet observed.

With respect to the effect of pain on cognition, experience of discomfort is commonly associated with impairment and may negatively affect activities of daily living (Moriarty, McGuire, & Finn, 2011). Such an effect may arise from competing neural resources, neuroplasticity (neural changes from pain) or altered neurochemistry (arising from opioid use). If there's a negative influence from pain on cognition, then the effect is substantial and plays a part on areas such as restriction of activity (Kreitler & Niv, 2007), which is related to poor stability (Stubbs, West, et al., 2014). In essence, pain may negatively influence cognition via distraction, neural change or from chemical interference (e.g., drowsiness) which can have a flow on effect of reduced activity. And reduced activity is correlated with poor stability.

While it has been noted in this thesis that OA groups were significantly less physically active when compared with asymptomatic older adults, relatively high

executive function assessment does not appear to have a deleterious influence on stability. At least on the measures presented in this thesis. It should be noted that, again, this was a convenience sample taken from the overall sample Chapter 4 of this thesis, and while the preliminary data suggests executive function has no influence on stability, a larger sample may well yield different results.

7.1.4 Can biomechanical response to perturbation predict falls in older adults with knee osteoarthritis?

Identification of biomechanical measures that predict falls in older adults with knee OA has, to date, not been attempted. This thesis includes a modelling study that showed that, particularly in women, higher velocity of centre of mass and with negative (extension) knee moment during stability were predictive of future falls. However, caution should be taken when viewing these findings for generalisation due to the small sample size (n=24) used in this prediction model. A larger sample would be needed to reach higher probability in future models. In practice however, it appears that where women with knee OA are moving faster in anterior direction, and where they have a more extended knee position at foot contact, they are more likely to fall. While the scope of this thesis does not afford an answer to the gender biased biomechanics noted, there is supporting evidence within the literature for increased likelihood of falls in women.

First, and foremost, women are more likely to experience OA (Manlapaz et al., 2019; Rudolph et al., 2007; Sandell, 2012). The reasons for this are, as yet unclear but there is a possibility that varus-valgus alignment of the knee may have a part to play (Elahi, Cahue, Felson, Engelman, & Sharma, 2000; Wise et al., 2012). While it appears that such an alignment, in itself, does not increase falls risk (van der Esch et al., 2014) the multifactorial nature of OA may mean that any varus-valgus laxity might be a contributing factor. Secondly, women are more likely to fall regardless of whether the knee is asymptomatic (Li et al., 2020; Peeters et al., 2018), or if there is knee pain reported (Dore et al., 2015; Muraki et al., 2011; Ofori-Asenso et al., 2020). There have been a number of potential reasons for this identified, including stroke, aged 85 years or older, poor nutrition, alcohol consumption, high medication use and presence of comorbidities such as arthritis, diabetes myelitis, and osteoporosis (Chang & Do,

2015). Having said this, knee pain increases falls risk (van der Esch et al., 2014). And, finally, women partake in less physical activity than their male counterparts (Ylitalo et al., 2021). Reduced activity is a factor of poor physical function (Ylitalo et al., 2021), along with poor quadriceps femoris strength (Sowers et al., 2006), and poor strength of knee musculature has also been linked to increased falls risk (van der Esch et al., 2014).

Given the above suggested reasons relating to joint alignment, pain and strength which might explain poorer physical function in older women with knee OA and could explain the prediction of falling within this group. Fallers might have poor knee positioning of the recovery limb at foot contact, which is exacerbated via poor strength of knee extensors. Such a position leads to lack of absorption of landing force and reduced control of the velocity of the centre of mass.

7.3 Practical implications and future research

Arising from this thesis, possible clinical interventions might include:

1. Encouraging extension of the upper body during a fall (via proprioception along, or in combination with strength). Such a position might aid in the control of the motion of upper body mass, leading to greater stability in this group.
2. Maximising extension of the base of support (in particular step length and velocity) via concentric and eccentric strength training of the entire lower limb.
3. The perturbation itself could be used as a training tool. Carty (2012) showed that repeated exposure to such training resulted in adaptation from multiple to single step responses in healthy older adults.

With respect to future research, the following areas have been identified as needing further investigation:

1. Lower limb neuromuscular influence on stability –

Perhaps the main question arising from this research relates to how best to manage the most pressing, and well discussed, areas of concern related to older adults with, and without, knee OA. Poor extension to the base of support via short step length at low velocity. In order to step quickly and longer, there needs to be both speed and strength available through the lower limb. While Downie (2014) and Levinger (2016) have discussed strength, this was only in the quadriceps femoris and there was no discussion on activity of muscle, nor reaction time. Further research could employ electromyography, as well as strength assessment, of all major lower-limb phasic muscles (triceps surae, tibialis anterior, quadriceps femoris, hamstring and gluteals), to identify if strength and/or power training can influence step spatio-temporal variables.

2. Pain influence on stability –

As discussed in Chapter 5 of this thesis, the influence of pain on stability in this group reflects the current state of the literature in that there is limited relationship between the biomechanics of balance and pain. Further research could involve participants who experience both nociceptive and neuropathic pain, who report higher pain levels, and also a sample that includes progression of OA (minor, mild, moderate, and severe). Via this it may be possible to identify if it is a type, level or OA stage specific pain that is increasing falls risk in this population.

3. Step classification -

As noted through Chapter 4 of this thesis, there was no statistical difference in step response (single v multiple) between OA and controls in any of the trial types presented (normal, cognitive dual-task challenge and physical dual-task challenge). This finding would suggest that the OA group may be as stable as controls, which is supported by the more extended trunk position in the former group. However, it is unclear if step response was a result of the presence of OA, especially given similar response was employed by many of the control participants. Further research could investigate the biomechanics of stability from the perspective of step response, rather than presence of OA. The intent being to investigate if it is the biomechanical response, regardless of disease, that determines poor stability.

4. Biomechanics of falls by gender prospective study –

Chapter 6 of this thesis addressed the possibility of predicting falls in older adults with knee OA using a modelling approach, and within the findings it was observed that women were more likely to fall in the presence of high velocity of centre of mass, and greater negative (extension) knee moment. Further research could involve investigation into the reasons for such a relationship in order to provide further data for interventions to aid women with OA in particular.

7.4 Limitations

There are several limitations in the studies presented in this work:

Firstly, the small sample size, particularly in Chapter 5 may influence the outcomes. Larger samples could clarify relationship, or lack of, between measures included in this chapter.

Secondly, the relative imbalance between groups in Chapter 4 of this thesis, may also misrepresent findings via either under or over-stating the relative importance of measures associated with stability in older adults with knee OA. While the sample maybe small, unbalanced and not representative of OA broadly, the findings are valid for participants in this study.

Finally, with respect to the prediction study (Chapter 6) the small sample size (n = 24) included only allows for prediction probabilities ± 0.2 (out of 1.0) with 95% CI. In order to predict probabilities within ± 0.1 with 95% CI, a sample of n = 96 would be necessary.

7.5 Conclusion

Collectively, the results from the studies in this thesis suggest that older adults with knee OA, while taking shorter and slower steps, are no more prone to employing a multi-step recovery strategy following perturbation than are asymptomatic controls. This may be because this group maintained a more upright upper-body posture, which affords the individual better control of the majority of the body's mass during a fall. Moreover, increased fear of, and interference from pain was correlated with the lower hip flexion angles. Hip motion was also correlated with OA related pain, stiffness, and disruption to normal daily activities. This lower hip flexion angle might play a part in maintaining upright posture in this group. Finally, logistic regression modelling shows good potential for predicting future falls from biomechanical variables, more successfully in females.

Appendices

Appendix 1 – Phone screen

Do you have other painful joints?	Ankle [__] Hip [__] Spinal [__] Shoulders [__] Elbows [__]	
If you DON'T experience pain		
What makes you believe you have knee osteoarthritis? NOTES:	GP [__] Specialist [__] Other [__]	
Is the lack of pain related to either activity modification or medication to avoid feelings of pain in the knee?	Modification [__] Medication [__] Other [__]	
STIFFNESS		
Do you have morning knee stiffness?		
If yes to the above, for how long?		
General medical history	***Yes***	***No***
Do you have any other medical conditions not already discussed?		
If yes to the above, what conditions:		
Surgeries history		
Please outline surgeries you have had:		

In your DOMINANT (if bilateral) or AFFECTED (if unilateral) leg:	
Which leg is this?	Left [__] Right [__]
How many weeks/years have you had pain?	Weeks [__] Years [__]
On a scale of 0 – 10 how bad is that pain now? 0 1 2 3 4 5 6 7 8 9 10	
On a scale of 0 – 10 how bad was that pain in the last week on average? 0 1 2 3 4 5 6 7 8 9 10	

When do you most often feel pain?

TIME: Morning [__] Middle of day [__] Evening [__]
WHEN: In bed [__] Sitting [__] Active [__]

IF ACTIVE: Walking (flat surface) [__] Walking (uneven surface) [__]
Stairs (ascending) [__] Stairs (descending) [__]

NOTES:

How does the pain affect you?

In your NON-DOMINANT (if bilateral) leg		
Which leg is this?	Left [__] Right [__]	
How many weeks/years have you had pain?	Weeks [__] Years [__]	
On a scale of 0 – 10 how bad is that pain now? 0 1 2 3 4 5 6 7 8 9 10		
On a scale of 0 – 10 how bad was that pain in the last week on average? 0 1 2 3 4 5 6 7 8 9 10		

When do you most often feel pain?

TIME: Morning [__] Middle of day [__] Evening [__]
WHEN: In bed [__] Sitting [__] Active [__]

IF ACTIVE: Walking (flat surface) [__] Walking (uneven surface) [__]
Stairs (ascending) [__] Stairs (descending) [__]

NOTES:

Phone screening form

Name: _____ DOB __/__/__ Age: __

Address: _____

_____

Phone: (__) _____ / _____

Email: _____

Source: □ Senior □ Move.org.au □ Life.org.au □ Other _____

□ Radio □ clinic/village □ Presentation @ _____

General questions	***Yes***	***No***
Are you aged between 60 and 90 years?		
Do you live in care?		
When shopping, or going to the doctor are you able to walk without difficulty? Notes:		
Do you have a condition of the lower limb which has made it hard for you to walk? Notes:		
Have you been diagnosed with a neurological condition (such as Parkinsons, Post-Polio Syndrome or brain injury Notes:		
OA related questions (NICE clinical diagnosis criteria)	***Yes***	***No***
PAIN		
Do you have knee pain?		
In which knee do you experience this pain?	Left [__] Right [__] Both [__]	

Falls		
Have you fallen in the past 12 months? (including stumbling, or grabbing hold of rails)		
If yes to the above, how often? Descriptions:		
Are you concerned about falling?		
Do you take actions to avoid falling (ie holding on to rails going up or down stairs)?		

Appendix 2 – Participant information

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled 'Biomechanical, physiological and cognitive factors in balance recovery in older adults with knee osteoarthritis'.

This project is being conducted by a student researcher Calum Downie as part of a PhD study at Victoria University under the supervision of Professor. Rezaul Begg and Associate Professor Pazit Levinger from the College of Sport and Exercise Science.

Project explanation

Around one third of older adults fall each year making it among the most common causes of injury and hospital admissions for older Australians. For those who have knee osteoarthritis this rate of falling increases to more than half. To date, little is known about why older adults with knee osteoarthritis fall. This project will investigate how people with knee osteoarthritis respond when recovering their balance, and will determine whether factors such as pain level and executive function (a set of mental abilities that help you to plan and get things done) can affect balance recovery in older adults with knee osteoarthritis. This information will assist us to better understand the mechanisms behind falling in this population which will aid in informing future studies into interventions to prevent falls.

Who can participate in the study?

People who are between 60 and 90 years old that have knee osteoarthritis are invited to take part in this study. Therefore, you are invited to take part in the study if you (1) have had pain in your knee for the past 6 months or more (2) had at least one fall in the last 12 months or you are concerned you might have a fall and (3) able to walk at least 45 metres independently.

You cannot participate in the study if:

- You have had uncontrolled non-musculoskeletal conditions that would make testing difficult and uncomfortable for you, such as chronic obstructive airways disease and congestive heart failure.
- You have a pre-existing neurological or orthopaedic condition affecting walking.
- You have a neurological condition that affects lower limb strength (for example: stroke, polio);
- You have any of the following foot conditions: partial foot amputation or ulceration or foot fractures,
- You have difficulties remembering things

What will I be asked to do?

We would like you to complete a series of biomechanical, functional and physiological tests at the Victoria University Footscray Park campus. There will be two testing sessions, each of approximately 3 hours, 12 months apart. You will be asked to complete the following assessments:

- Recovering balance from a forwards lean (balance recovery tasks)
- Functional and balance tasks
- Strength tests
- Memory tests
- Questionnaires
- Falls calendar, completed daily and submitted monthly

You will also be videoed while conducting the balance recovery tasks.

What will I gain from participating?

While the information gained from participation in this study may not benefit you directly, you main gain a deeper understanding about your general risk of falling.

How will the information I give be used?

Data gathered during the course of this research project will be used for the thesis of Mr Calum Downie as part of the degree of Doctor of Philosophy, for scientific publications and/or presentations, with no means of you being identified, except with your permission.

Any information connected to this research which may be able to identify you will remain confidential. Data on your participation will have your identifying details removed and will used solely for research purposes. No information will be disclosed except where you have permitted, or as required by law.

All information will be stored securely in a locked filing cabinet in Professor Rezaul Begg's office in the College of Sport and Exercise Science at Victoria University. Access to this cabinet is limited to the student and supervisors of this project. Your information will also be stored on a password-protected and access limited research repository at Victoria University. Again only the student and supervisors have access to this location. For compliance with University ethics and research records management, your information will be kept for a period of five years from completion of the project. After this time, the information will be destroyed via secured records destruction and deletion of computer files.

What are the potential risks of participating in this project?

During the balance recovery tasks, you may fall as a result of not being able to complete the task. You will however, be protected from falling to the ground as you will be wearing a full body harness attached to an overhead frame. Furthermore, the task itself may cause some discomfort or pain in your affected knee. Throughout all testing you will be fully supervised by a staff member, and if at any time you feel uncomfortable you may stop.

The functional and balance tasks, while involving some physical risk, are designed to allow for safe and easy assessment of factors relating to balance and risk of falling. There exists a small risk of muscle strain and the potential to fall while completing these tests. You will be supervised by a staff member while completing these tests

How will this project be conducted?

Prior to enrolment in this study you will be asked a series of questions about both your physical and health status, from which we will determine if you are eligible to participate. Should you be eligible we will arrange a mutually suitable time for you to attend the Victoria University Footscray Park campus, during which the following assessments will take place:

Balance recovery tasks:

This task measures how you move, and in particular how you recover from a simulated fall. You will wear a full body harness that allows for freedom of movement, while protecting you from an actual fall and contact with the floor. You will be placed in a forwards lean position to simulate a fall, and, once in this position, you will be released and you will need to regain your balance. You will also be asked to complete this task while counting backwards, while crossing a small 4cm foam obstacle and without either of these conditions. Prior to commencing these tasks you will be given opportunity to complete some practice trials to become familiar with the process.

To complete these tasks you will be asked to wear shorts and a singlet which will expose both your legs and tummy. Small reflective markers will be attached to your head, shoulders, arms, torso, pelvis, legs and feet. These will be attached by double sided hypoallergenic tape. These markers will be used to capture your movement when you recover your balance. There will also be a single video camera recording your movements from the side which is not likely to identify your face. The video from this camera is used to aid in classification of your movements and will not be used in either presentations or publications without your consent.

Function and balance tasks:

You will be asked to complete the following functional and balance assessment tasks:

- Quickscreen: we will test your vision, joint sense, balance, and reaction time
- Knee strength: we will test your knee muscle strength while in a machine designed to measure muscle strength
- Fast Timed up and Go: you will rise from a chair, walk around a cone 3m away, and return to the seated position as quickly as you can. You will do this with two conditions, in one you will carry a glass of water and in the other you will be counting backwards.
- Four Square Step Test: you be step into four squares in order moving sideways, backwards and forwards as quick as you can
- Rapid Stepping Test: you will step forwards, backwards or the side as quickly as possible after being given the direction to step by the researcher
- Trail Making Test (A&B): you will be assessed on your ability to process information and perform tasks and the ability to switch between tasks. You will be required to connect numbers with a line and letters with numbers
- Stroop Colour Word Test: will be used to assess selective attention, the ability to stop incorrect responses, and how long it takes to choose a response
- Wechsler Memory Scale-III Test: will be used to assess the ability to hold information in memory and use it to perform tasks. You will be presented with a string of numbers by the examiner and you will be asked to repeat them back exactly as they were presented

Questionnaires:

You will also be asked to complete a number of questionnaires regarding your health status, pain, how your pain affects your daily function, fear of falls, your level of physical activities, falls history and overall quality of life.

- Pain questionnaires:
    - Brief Pain Inventory Short Form: how you rate your general pain at the time of testing, how you manage that pain and how the pain has interfered with your normal life
    - Pain DETECT: how you perceive pain specific to the knee joint at the time of testing, in the weeks leading up to that day, and how what things might trigger that pain
    - Western Ontario and McMaster Universities Arthritis Index: your pain, stiffness and physical function in the period immediately before testing (48 hours)
    - Fear of Pain: measures your fear of pain itself in common situations, and your anxiety associated with that pain
    - Pain Catastrophizing Scale: how you perceive pain in general terms, whether you think about it and how you feel about it
- Falls and quality of life questionnaires:
    - Falls Efficacy Scale: your fear of falling during your normal daily activities
    - Assessment of Quality of Life: assess your overall quality of life in relation to areas including medication, your ability to complete household tasks and live independently, how your health status impacts on your relationships and how your vision and hearing impact on your ability to communicate
    - Physical Activity: assesses your normal levels of physical activity

Who is conducting the study?

This project is being conducted by a student researcher Calum Downie as part of a PhD study at Victoria University within the College of Sport and Exercise Science under the supervision of Professor Rezaul Begg, and Associate Professor Pazit Levinger.

For details or to arrange a meeting please contact My Calum Downie via: Phone: (03) 9919 5585
Email: calum.downie@vu.edu.au

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

Appendix 3 – Participant consent form

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study titled "**Biomechanical, physiological and cognitive factors in balance recovery in older adults with knee osteoarthritis**".

The project will investigate how people with knee osteoarthritis respond when recovering their balance, and will determine whether factors such as pain level and poor executive function (a set of mental abilities that help you to plan and get things done) can affect balance recovery performance in older adults with knee osteoarthritis.

CERTIFICATION BY SUBJECT

I, _____(participant's name)

of _____

_____(your full address including suburb)

certify that I am at least 60 years old and that I am voluntarily giving my consent to participate in the study: **Biomechanical, physiological and cognitive factors in balance recovery in older adults with knee osteoarthritis** being conducted at Victoria University by: the student researcher Calum Downie as part of a Doctor of Philosophy at Victoria University under the supervision of Professor Rezaul Begg and Associate Professor Pazit Levinger from the College of Sport and Exercise Science.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

_____(name of researcher)

and that I freely consent to participation involving the below mentioned procedures:

- ☐ Balance recovery tests
- ☐ Functional and balance tests
- ☐ Questionnaires
- ☐ Video capture of balance recovery tests

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: _____Date: _____

Any queries about your participation in this project may be directed to the researchers:
Calum Downie (03) 9919 5585, add email address

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001, email Researchethics@vu.edu.au or phone (03) 9919 4781 or 4461.

V.1/2013 1 of 1

Appendix 4 – SLUMS test

VAMC
SLUMS Examination

Questions about this assessment tool? E-mail aging@slu.edu.

Name_____ Age _____

Is patient alert?_____ Level of education _____

__/1 (1) 1. What day of the week is it?

__/1 (1) 2. What is the year?

__/1 (1) 3. What state are we in?

4. Please remember these five objects. I will ask you what they are later.
Apple Pen Tie House Car

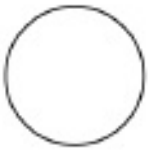
5. You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.
(1) How much did you spend?
__/3 (2) How much do you have left?

6. Please name as many animals as you can in one minute.
__/3 (0) 0-4 animals (1) 5-9 animals (2) 10-14 animals (3) 15+ animals

__/5 7. What were the five objects I asked you to remember? 1 point for each one correct.

8. I am going to give you a series of numbers and I would like you to give them to me backwards. For example, if I say 42, you would say 24.
__/2 (0) 87 (1) 649 (1) 8537

9. This is a clock face. Please put in the hour markers and the time at ten minutes to eleven o'clock.



(2) Hour markers okay
__/4 (2) Time correct

__/2 (1) 10. Please place an X in the triangle.

(1) Which of the above figures is largest?

11. I am going to tell you a story. Please listen carefully because afterwards, I'm going to ask you some questions about it.
Jill was a very successful stockbroker. She made a lot of money on the stock market. She then met Jack, a devastatingly handsome man. She married him and had three children. They lived in Chicago. She then stopped work and stayed at home to bring up her children. When they were teenagers, she went back to work. She and Jack lived happily ever after.

(2) What was the female's name?
(2) What work did she do?
__/8 (2) When did she go back to work?
(2) What state did she live in?

_____ TOTAL SCORE

Department of Veterans Affairs

SAINT LOUIS UNIVERSITY

SCORING

High School Education		Less than High School Education
27-30	Normal	25-30
21-26	MNCD*	20-24
1-20	Dementia	1-19

* Mild Neurocognitive Disorder

SH Tariq, N Tumosa, JT Chibnall, HM Perry III, and JE Morley. The Saint Louis University Mental Status (SLUMS) Examination for Detecting Mild Cognitive Impairment and Dementia is more sensitive than the Mini-Mental Status Examination (MMSE) - A pilot study. Am J Geriatr Psychiatry 14:900-910, 2006.

Appendix 5 – Condition investigation

VICTORIA UNIVERSITY MELBOURNE AUSTRALIA CELEBRATING A CENTENARY OF OPPORTUNITY 2016

Condition investigation

Participant Code:	_____		Age: __		
Affected limb:	Left	[__]	Dominant limb:	Left	[__]
	Right	[__]		Right	[__]
	Both	[__]			
Session:	Baseline	[__]	Follow-up	[__]	

General questions	***Yes***	***No***
Are you aged between 60 and 90 years?		
Do you live in care?		
When shopping, or going to the doctor are you able to walk without difficulty? Notes:		
Do you have a condition of the lower limb which has made it hard for you to walk? Notes:		
Have you been diagnosed with a neurological condition (such as Parkinsons, Post-Polio Syndrome or brain injury Notes:		
OA related questions (NICE clinical diagnosis criteria)	***Yes***	***No***
PAIN		
Do you have knee pain?		
In which knee do you experience this pain?	Left [__] Right [__] Both [__]	
In your DOMINANT (if bilateral) or AFFECTED (if unilateral) leg:		
Which leg is this?	Left [__] Right [__]	
How many weeks/years have you had pain?	Weeks [__]	

										Years	[__]
On a scale of 1 – 10 how bad is that pain now?	1	2	3	4	5	6	7	8	9	10	
On a scale of 1 – 10 how bad was that pain in the last week on average?	1	2	3	4	5	6	7	8	9	10	

When do you most often feel pain?

TIME:	Morning [__]	Middle of day [__]	Evening [__]
WHEN:	In bed [__]	Sitting [__]	Active [__]
IF ACTIVE:	Walking (flat surface) [__]		Walking (uneven surface) [__]
	Stairs (ascending) [__]		Stairs (descending) [__]

NOTES:

How does the pain affect you?

In your NON-DOMINANT (if bilateral) leg		
Which leg is this?	Left	[__]
	Right	[__]
How many weeks/years have you had pain?	Weeks	[__]
	Years	[__]

On a scale of 1 – 10 how bad is that pain now?	1	2	3	4	5	6	7	8	9	10	
On a scale of 1 – 10 how bad was that pain in the last 24 hours?	1	2	3	4	5	6	7	8	9	10	

When do you most often feel pain?

TIME:	Morning [__]	Middle of day [__]	Evening [__]
WHEN:	In bed [__]	Sitting [__]	Active [__]
IF ACTIVE:	Walking (flat surface) [__]		Walking (uneven surface) [__]
	Stairs (ascending) [__]		Stairs (descending) [__]

NOTES:

Descriptions:		
Are you concerned about falling?		
Do you take actions to avoid falling (ie holding on to rails going up or down stairs)?		

Appendix 5 – Medication recording

Medication Recording

PARTICIPANT CODE:	*SESSION:*	*DATE:*	
Medication	*For what*	*Dose*	*Prescription (P) Off the shelf (O) Supplement (S)*

Have you taken any pain killers in the past 24-48 hours? *YES / NO*

If yes, what have you taken:

_____
_____
_____
_____
_____
_____
_____
_____
_____

_____

Appendix 6 – Trail Making Test A & B

Trail Making Test (TMT) Parts A & B

Instructions:

Both parts of the Trail Making Test consist of 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the patient should draw lines to connect the numbers in ascending order. In Part B, the circles include both numbers (1 – 13) and letters (A – L); as in Part A, the patient draws lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The patient should be instructed to connect the circles as quickly as possible, without lifting the pen or pencil from the paper. Time the patient as he or she connects the "trail." If the patient makes an error, point it out immediately and allow the patient to correct it. Errors affect the patient's score only in that the correction of errors is included in the completion time for the task. It is unnecessary to continue the test if the patient has not completed both parts after five minutes have elapsed.

Step 1:	Give the patient a copy of the Trail Making Test Part A worksheet and a pen or pencil.
Step 2:	Demonstrate the test to the patient using the sample sheet (Trail Making Part A – *SAMPLE*).
Step 3:	Time the patient as he or she follows the "trail" made by the numbers on the test.
Step 4:	Record the time.
Step 5:	Repeat the procedure for Trail Making Test Part B.

Scoring:

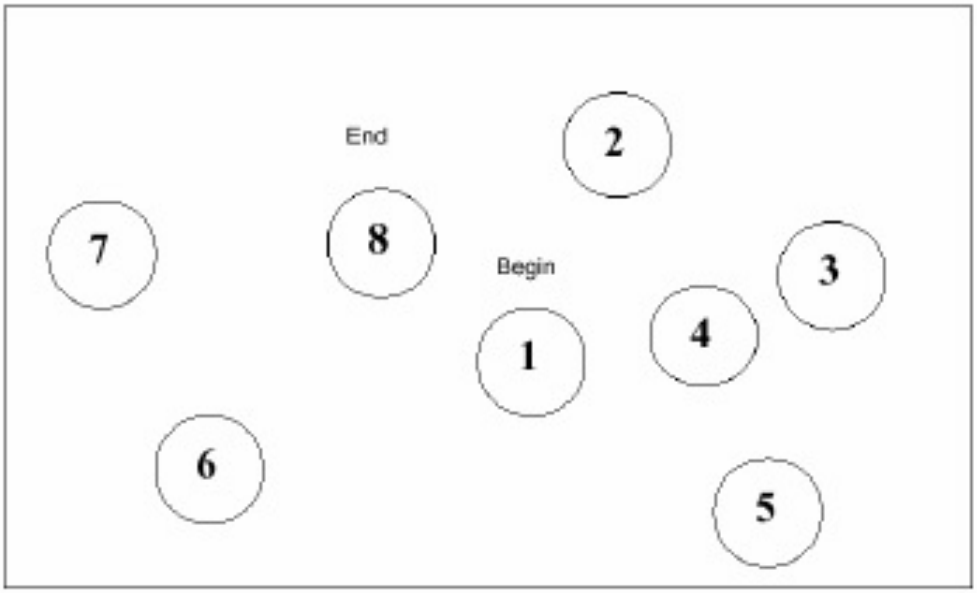
Results for both TMT A and B are reported as the number of seconds required to complete the task; therefore, higher scores reveal greater impairment.

	Average	Deficient	Rule of Thumb
Trail A	29 seconds	> 78 seconds	Most in 90 seconds
Trail B	75 seconds	> 273 seconds	Most in 3 minutes

Sources:

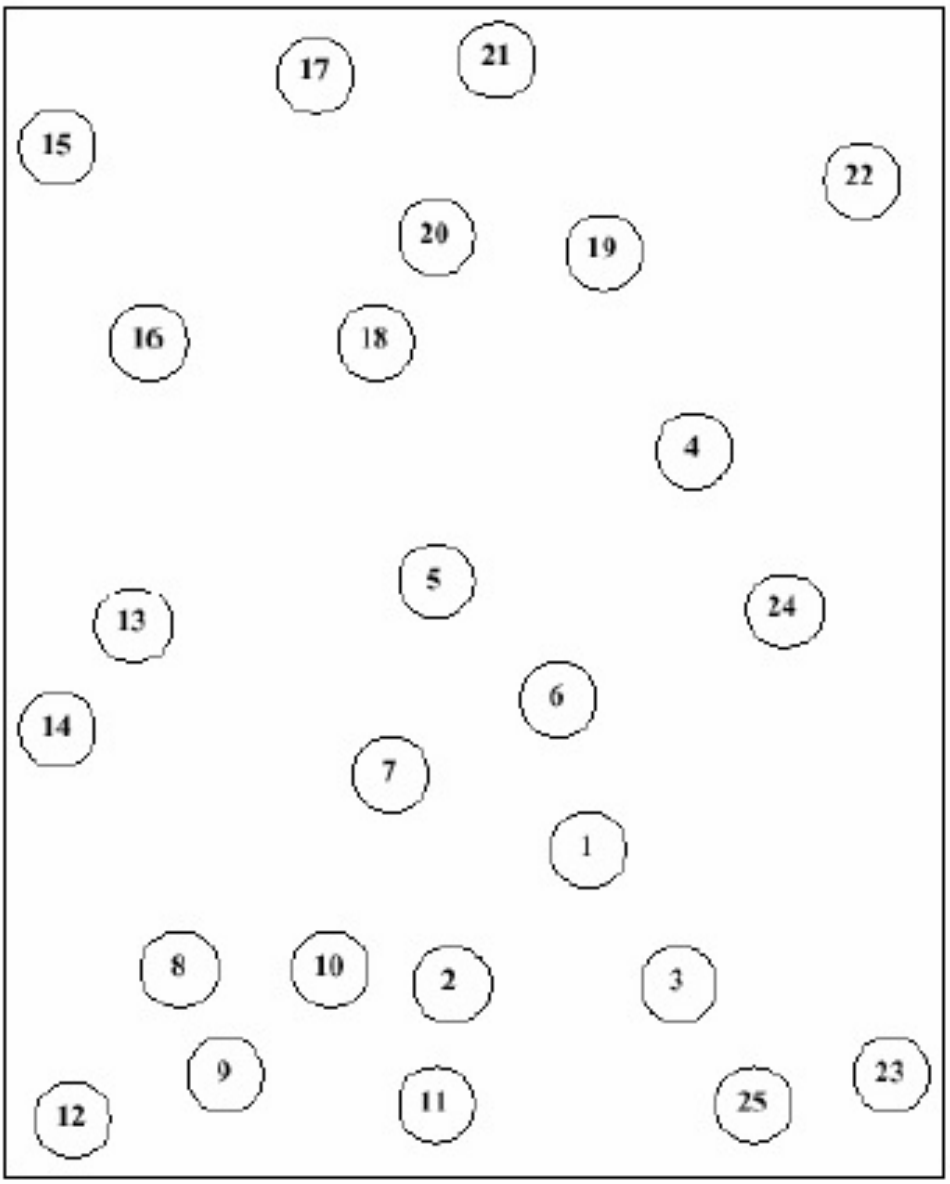
- Corrigan JD, Hinkeldey MS. Relationships between parts A and B of the Trail Making Test. *J Clin Psychol.* 1987;43(4):402–409.
- Gaudino EA, Geisler MW, Squires NK. Construct validity in the Trail Making Test: what makes Part B harder? *J Clin Exp Neuropsychol.* 1995;17(4):529-535.
- Lezak MD, Howieson DB, Loring DW. *Neuropsychological Assessment.* 4th ed. New York: Oxford University Press; 2004.
- Reitan RM. Validity of the Trail Making test as an indicator of organic brain damage. *Percept Mot Skills.* 1958;8:271-276.

Trail Making Test Part A – *SAMPLE*

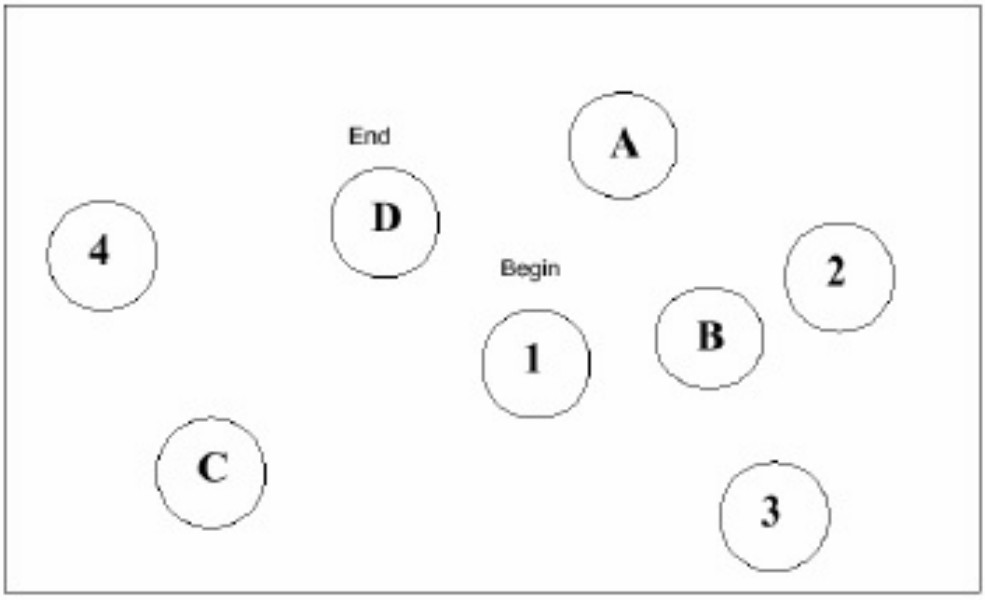


Trail Making Test Part A

Patient's Name: _____ Date: _____

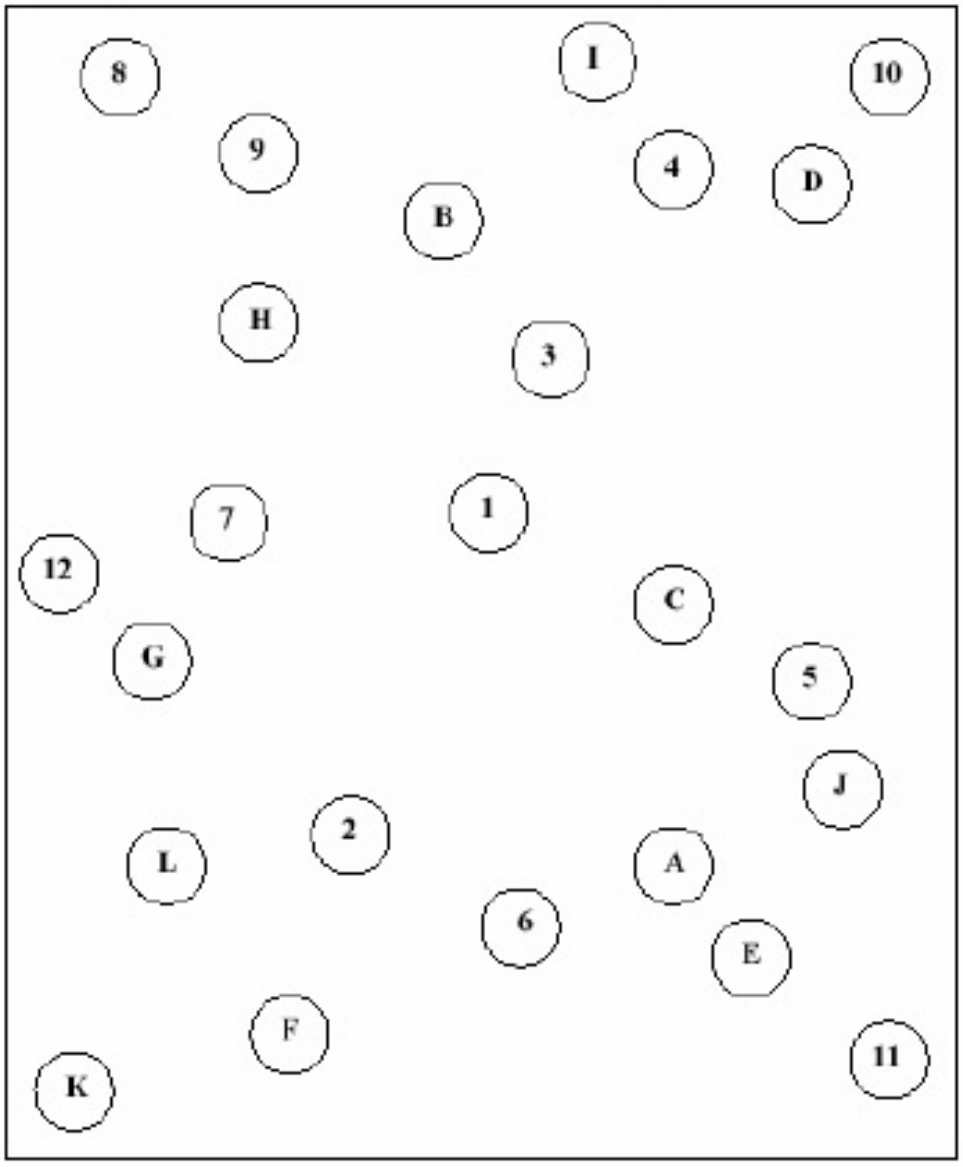


Trail Making Test Part B – *SAMPLE*

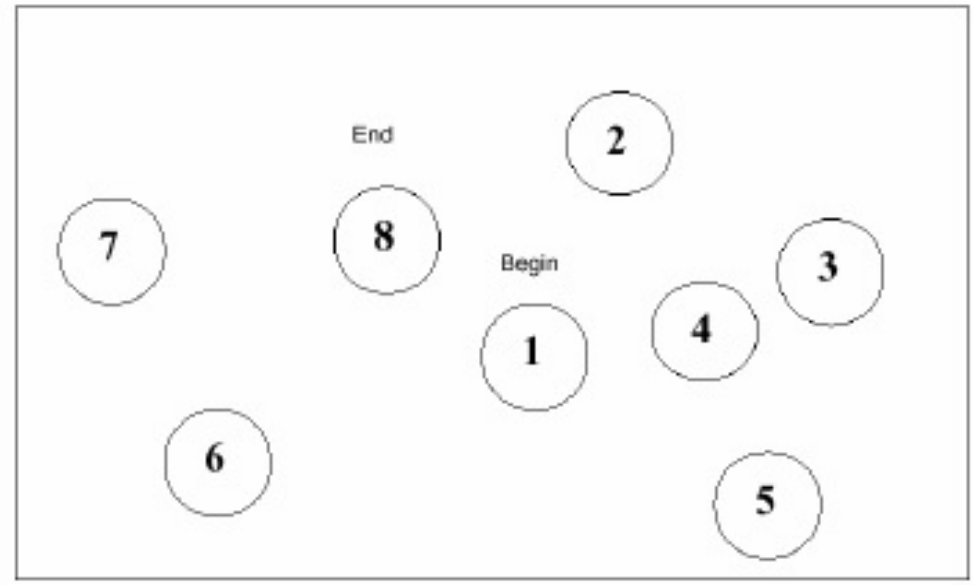


Trail Making Test Part B

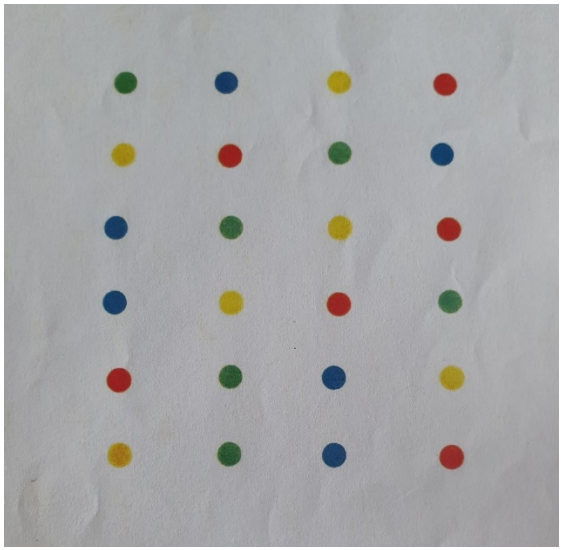
Patient's Name: _____ Date: _____

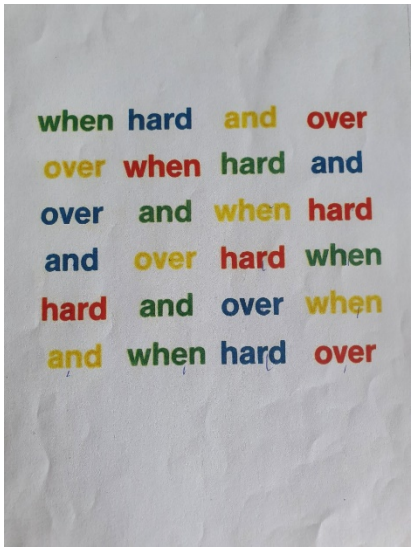


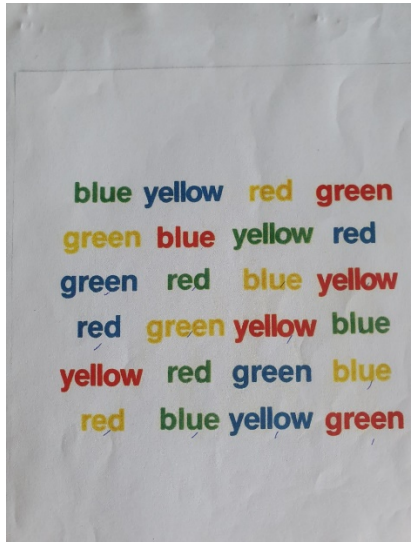
Trail Making Test Part A – *SAMPLE*



Appendix 7 – Stroop Colour and Word test







Appendix 8 – Wechsler Memory Scale III Digit Span

Wechsler Memory Scale-III

DIGITS FORWARDS

Item	First trial	√ or X	Second trial	√ or X	Total
A	43		16		
B	792		847		
C	5941		7253		
D	93872		75396		
E	152849		216748		
F	3745261		4925316		
G	82973546		69174253		
H	246937185		371625948		
				Forwards score:	

DIGITS BACKWARDS

Item	Trial one	√ or X	Trial two	√ or X	Total
A	83		29		
B	475		615		
C	2619		3852		
D	28736		59413		
E	624719		276391		
F	4183627		1586937		
G	52624197		94617385		
				Backwards score:	

FINAL SCORE:

Total forwards and backwards:	
Standard score:	
Percentile equivalent:	

Martin Turner
Jacky Ridsdale
revised 6th October 2004

Appendix 9 – Brief Pain Inventory (Short Form)

1909

Date: ☐☐ / ☐☐ / ☐☐
(month) (day) (year)

Subject's Initials : _____

Study Subject #: ☐☐☐☐

Study Name: _____

Protocol #: _____

PI: _____

Revision: 07/01/05

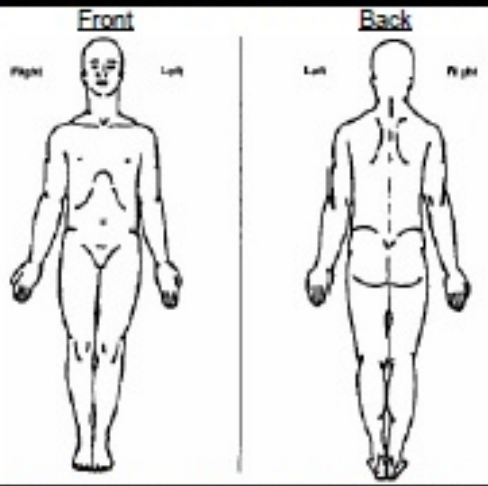
PLEASE USE BLACK INK PEN

Brief Pain Inventory (Short Form)

1. Throughout our lives, most of us have had pain from time to time (such as minor headaches, sprains, and toothaches). Have you had pain other than these everyday kinds of pain today?

☐ Yes ☐ No

2. On the diagram, shade in the areas where you feel pain. Put an X on the area that hurts the most.



3. Please rate your pain by marking the box beside the number that best describes your pain at its worst in the last 24 hours.

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

No Pain — Pain As Bad As You Can Imagine

4. Please rate your pain by marking the box beside the number that best describes your pain at its least in the last 24 hours.

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

No Pain — Pain As Bad As You Can Imagine

5. Please rate your pain by marking the box beside the number that best describes your pain on the average.

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

No Pain — Pain As Bad As You Can Imagine

6. Please rate your pain by marking the box beside the number that tells how much pain you have right now.

☐0 ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10

No Pain — Pain As Bad As You Can Imagine

1903

Date: (month) / (day) / (year)

Subject's Initials: _____

Study Subject #:

PLEASE USE BLACK INK PEN

Study Name: _____

Protocol #: _____

PI: _____

Revision: 07/01/05

7. What treatments or medications are you receiving for your pain?

8. In the last 24 hours, how much relief have pain treatments or medications provided? Please mark the box below the percentage that most shows how much relief you have received.

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
☐ No Relief	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐ Complete Relief

9. Mark the box beside the number that describes how, during the past 24 hours, pain has interfered with your:

A. General Activity

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

B. Mood

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

C. Walking ability

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

D. Normal Work (includes both work outside the home and housework)

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

E. Relations with other people

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

F. Sleep

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

G. Enjoyment of life

☐ 0 Does Not Interfere ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Completely Interferes

Appendix 10 – PainDETECT

painDETECT

PAIN QUESTIONNAIRE

Date: _____ Patient: Last name: _____ First name: _____

How would you assess your pain **now**, at this moment?

0 1 2 3 4 5 6 7 8 9 10

none max.

How strong was the **strongest** pain during the past 4 weeks?

0 1 2 3 4 5 6 7 8 9 10

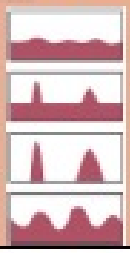
none max.

How strong was the pain during the past 4 weeks on average?

0 1 2 3 4 5 6 7 8 9 10

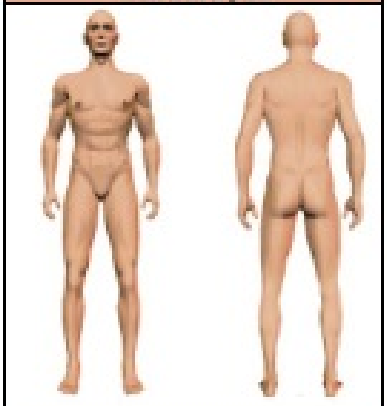
none max.

Mark the picture that best describes the course of your pain:



- Persistent pain with slight fluctuations ☐
- Persistent pain with pain attacks ☐
- Pain attacks without pain between them ☐
- Pain attacks with pain between them ☐

Please mark your main area of pain



Does your pain radiate to other regions of your body? yes ☐ no ☐

If yes, please draw the direction in which the pain radiates

Do you suffer from a burning sensation (e.g., stinging nettles) in the marked areas?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Do you have a tingling or prickling sensation in the area of your pain (like crawling ants or electrical tingling)?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Is light touching (clothing, a blanket) in this area painful?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Do you have sudden pain attacks in the area of your pain, like electric shocks?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Is cold or heat (bath water) in this area occasionally painful?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Do you suffer from a sensation of numbness in the areas that you marked?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

Does slight pressure in this area, e.g., with a finger, trigger pain?

never ☐ hardly noticed ☐ slightly ☐ moderately ☐ strongly ☐ very strongly ☐

(To be filled out by the physician)

never	hardly noticed	slightly	moderately	strongly	very strongly
☐ x 0 = 0	☐ x 1 = ☐	☐ x 2 = ☐☐	☐ x 3 = ☐☐	☐ x 4 = ☐☐	☐ x 5 = ☐☐

Total score ☐☐ out of 35

Development/Reference: R. Freynhagen, R. Baron, U. Gockel, T.R. Tölle / Curr Med Res Opin, Vol.22, No. 10 (2006)

painDETECT

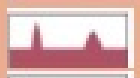
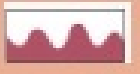
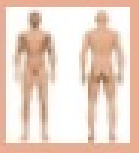
SCORING OF PAIN QUESTIONNAIRE

Date: _____ Patient: Last name: _____ First name: _____

Please transfer the total score from the pain questionnaire:

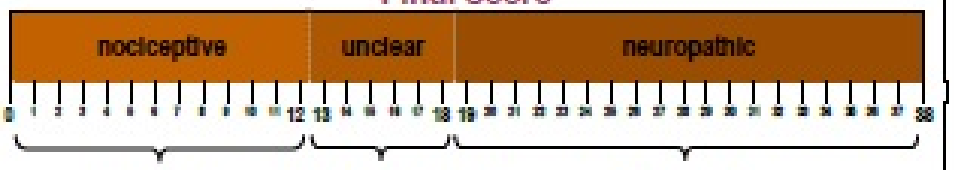
Total score | |

Please add up the following numbers, depending on the marked pain behavior pattern and the pain radiation. Then total up the final score:

	Persistent pain with slight fluctuations	0	
	Persistent pain with pain attacks	- 1	If marked, or
	Pain attacks without pain between them	+ 1	If marked, or
	Pain attacks with pain between them	+ 1	If marked
	Radiating pains?	+ 2	If yes
	Final score		

Screening Result

Final score



A neuropathic pain component is unlikely (< 15%)

Result is ambiguous, however a neuropathic pain component can be present

A neuropathic pain component is likely (> 90%)

This sheet does not replace medical diagnostics.
It is used for screening the presence of a neuropathic pain component.

Development/Reference: R. Freynhagen, R. Baron, U. Gockel, T.R. Tölle / Curr Med Res Opin, Vol.22, No. 10 (2006)

Appendix 11 – WOMAC

WOMAC Osteoarthritis Index LK3.1 (IK)

INSTRUCTIONS TO PATIENTS

In Sections A, B, and C questions are asked in the following format. Please mark your answers by putting an " ✗ " in one of the boxes.

EXAMPLES:

1. If you put your " ✗ " in the box on the far left as shown below,

none	mild	moderate	severe	extreme
☒	☐	☐	☐	☐

then you are indicating that you feel **no** pain.

2. If you put your " ✗ " in the box on the far right as shown below,

none	mild	moderate	severe	extreme
☐	☐	☐	☐	☒

then you are indicating that you feel **extreme** pain.

3. Please note:
   a) that the further to the right you place your " ✗ ", the **more** pain you feel.
   b) that the further to the left you place your " ✗ ", the **less** pain you feel.
   c) **please do not** place your " ✗ " **outside any of the boxes.**

You will be asked to indicate on this type of scale the amount of pain, stiffness or disability you have felt during the last 48 hours.

Think about your knee to be injected when answering the questions. Indicate the severity of your pain and stiffness and the difficulty you have in doing daily activities that you feel are caused by the arthritis in your knee to be injected.

Your knee to be injected has been identified for you by your health care professional. If you are unsure which knee is to be injected, please ask before completing the questionnaire.

V3 - English for USA
(at baseline)

WOMAC Osteoarthritis Index LK3.1 (IK)

Section A

PAIN

Think about the pain you felt during the last 48 hours caused by the arthritis in your knee to be injected.

(Please mark your answers with an " ✗ ".)

QUESTION: **How much pain have you had . . .**					Study Coordinator Use Only
1. when walking on a flat surface?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PAIN1 _____
2. when going up or down stairs?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PAIN2 _____
3. at night while in bed? (that is - pain that disturbs your sleep)					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PAIN3 _____
4. while sitting or lying down?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PAIN4 _____
5. while standing?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PAIN5 _____

V3 - English for USA
(at baseline)

WOMAC Osteoarthritis Index LK3.1 (IK)

Section B

STIFFNESS

Think about the stiffness (not pain) you felt during the last 48 hours caused by the arthritis in your knee to be injected.

Stiffness is a sensation of **decreased** ease in moving your joint.

(Please mark your answers with an " ✗ ".)

	Study Coordinator Use Only
6. How **severe** has your stiffness been **after you first woke up** in the morning? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	STIFF6 _____
7. How **severe** has your stiffness been after sitting or lying down or while resting **later in the day**? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	STIFF7 _____

WOMAC Osteoarthritis Index LK3.1 (IK)

Section C

DIFFICULTY PERFORMING DAILY ACTIVITIES

Think about the difficulty you had in doing the following daily physical activities during the last 48 hours caused by the arthritis in your knee to be injected. By this we mean **your ability to move around and take care of yourself.**

(Please mark your answers with an " ✗ ".)

QUESTION: **How much difficulty have you had . . .**					Study Coordinator Use Only
8. when going down the stairs?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN8 _____
9. when going up the stairs?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN9 _____
10. when getting up from a sitting position?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN10 _____
11. while standing?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN11 _____
12. when bending to the floor?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN12 _____
13. when walking on a flat surface?					
none ❑	mild ❑	moderate ❑	severe ❑	extreme ❑	PFTN13 _____

V3 - English for USA
(at baseline)

WOMAC Osteoarthritis Index LK3.1 (IK)

DIFFICULTY PERFORMING DAILY ACTIVITIES

Think about the difficulty you had in doing the following daily physical activities during the last 48 hours caused by the arthritis in your knee to be injected. By this we mean **your ability to move around and take care of yourself**.

(Please mark your answers with an " ✗ ".)

QUESTION: **How much difficulty have you had . . .**	Study Coordinator Use Only
14. getting in or out of a car, or getting on or off a bus? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN14 _____
15. while going shopping? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN15 _____
16. when putting on your socks or panty hose or stockings? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN16 _____
17. when getting out of bed? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN17 _____
18. when taking off your socks or panty hose or stockings? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN18 _____
19. while lying in bed? none ❑ mild ❑ moderate ❑ severe ❑ extreme ❑	PFTN19 _____

V3 - English for USA
(at baseline)

WOMAC Osteoarthritis Index LK3.1 (IK)

DIFFICULTY PERFORMING DAILY ACTIVITIES

Think about the difficulty you had in doing the following daily physical activities during the last 48 hours caused by the arthritis in your knee to be injected. By this we mean **your ability to move around and take care of yourself**.

(Please mark your answers with an " ✗ ".)

QUESTION: **How much difficulty have you had . . .**	none	mild	moderate	severe	extreme	Study Coordinator Use Only
20. when getting in or out of the bathtub?	❑	❑	❑	❑	❑	PFTN20 _____
21. while sitting?	❑	❑	❑	❑	❑	PFTN21 _____
22. when getting on or off the toilet?	❑	❑	❑	❑	❑	PFTN22 _____
23. while doing heavy household chores?	❑	❑	❑	❑	❑	PFTN23 _____
24. while doing light household chores?	❑	❑	❑	❑	❑	PFTN24 _____

V3 - English for USA
(at baseline)

Appendix 12 – FPQ

FEAR OF PAIN QUESTIONNAIRE – III

Name:_____ Date:_____

INSTRUCTIONS: The items listed below describe painful experiences. Please look at each item and think about how **FEARFUL** you are of experiencing the **PAIN** associated with each item. If you have never experienced the **PAIN** of a particular item, please answer on the basis of how **FEARFUL** you expect you would be if you had such an experience. Circle one number for each item below to rate your **FEAR OF PAIN** in relation to each event.

	Not At All	A Little	A Fair Amount	Very Much	Extreme
I FEAR the PAIN associated with:					
1. Being in an automobile accident.	1	2	3	4	5
2. Biting your tongue while eating.	1	2	3	4	5
3. Breaking your arm.	1	2	3	4	5
4. Cutting your tongue licking an envelope.	1	2	3	4	5
5. Having a heavy object hit you in the head.	1	2	3	4	5
6. Breaking your leg.	1	2	3	4	5
7. Hitting a sensitive bone in your elbow – your "funny bone."	1	2	3	4	5
8. Having a blood sample drawn with a hypodermic needle.	1	2	3	4	5
9. Having someone slam a heavy car door on your hand.	1	2	3	4	5
10. Falling down a flight of concrete stairs.	1	2	3	4	5
11. Receiving an injection in your arm.	1	2	3	4	5
12. Burning your fingers with a match.	1	2	3	4	5
13. Breaking your neck.	1	2	3	4	5
14. Receiving an injection in your hip/buttocks.	1	2	3	4	5
15. Having a deep splinter in the sole of your foot probed and removed with tweezers.	1	2	3	4	5

Questions Continue on Next Page →

	Not At All	A Little	A Fair Amount	Very Much	Extreme
I FEAR the PAIN associated with:					
16. Having an eye doctor remove a foreign particle stuck in your eye.	1	2	3	4	5
17. Receiving an injection in your mouth.	1	2	3	4	5
18. Being burned on your face by a lit cigarette.	1	2	3	4	5
19. Getting a paper-cut on your finger.	1	2	3	4	5
20. Receiving stitches in your lip.	1	2	3	4	5
21. Having a foot doctor remove a wart from your foot with a sharp instrument.	1	2	3	4	5
22. Cutting yourself while shaving with a sharp razor.	1	2	3	4	5
23. Gulping a hot drink before it has cooled.	1	2	3	4	5
24. Getting strong soap in both your eyes while bathing or showering.	1	2	3	4	5
25. Having a terminal illness that causes you daily pain.	1	2	3	4	5
26. Having a tooth pulled.	1	2	3	4	5
27. Vomiting repeatedly because of food poisoning.	1	2	3	4	5
28. Having sand or dust blow into your eyes.	1	2	3	4	5
29. Having one of your teeth drilled.	1	2	3	4	5
30. Having a muscle cramp.	1	2	3	4	5

Appendix 13 – PCS

Pain Catastrophizing Scale

Sullivan MJL, Bishop S, Pivik J. (1995)

Name:	Age:	Gender:	Date:
----------	----------	☐Male ☐Female	----------

Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

Instructions:
We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

RATING	0	1	2	3	4
MEANING	Not at all	To a slight degree	To a moderate degree	To a great degree	All the time

When I'm in pain …

Number	Statement	Rating
1	I worry all the time about whether the pain will end.	
2	I feel I can't go on.	
3	It's terrible and I think it's never going to get any better	
4	It's awful and I feel that it overwhelms me.	
5	I feel I can't stand it anymore	
6	I become afraid that the pain will get worse.	
7	I keep thinking of other painful events	
8	I anxiously want the pain to go away	
9	I can't seem to keep it out of my mind	
10	I keep thinking about how much it hurts.	
11	I keep thinking about how badly I want the pain to stop	
12	There's nothing I can do to reduce the intensity of the pain	
13	I wonder whether something serious may happen.	

Source: Sullivan M.J.L., Bishop S, Pivik J. The pain catastrophizing scale: development and validation. *Psychol Assess*; 1995, 7: 524-532

Appendix 14 – Falls Calendar

Month/Year

Instructions: At the end of each day, please place an X in the box for that day ***if you fell.***						
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	☐ ***I had no falls this month***			

Please telephone Mr. Calum Downie when you have a fall, even if it was a minor fall.

Phone number (03) 9919 5585

PLEASE MAIL THIS SHEET IN THE AN INCLUDED SELF-ADDRESSED ENVELOPE AS SOON AS POSSIBLE FOLLOWING THE MONTH END.

CODE: xxx

Appendix 15 – Best fit additive model performance (ROC analysis)

Using all 7 variables and their various combinations. The best model in terms of AUC is the model with COM_VEL, KNEE_MOM, and SUBJ_GEN as the predictors with AUC of 0.656. The table below gives sorted AUC versus variables included in the 128 possible models (0=excluded, 1=included).

	COM_VEL	KNEE_ANG	KNEE_MOM	KNEE_ANG_VEL	SUBJ_GEN	NUM_MEDS	COMORBS	rocresults
1	1	0	1	0	1	0	0	0.6562500
2	1	0	1	0	1	0	1	0.6250000
3	1	0	1	1	1	0	0	0.5937500
4	1	1	1	0	1	0	0	0.5781250
5	0	0	1	0	1	0	0	0.5625000
6	1	0	1	0	1	1	0	0.5625000
7	1	1	1	0	1	0	1	0.5625000
8	1	0	1	1	1	0	1	0.5625000
9	1	0	1	0	1	1	1	0.5625000
10	0	0	0	0	1	0	1	0.5390625
11	1	1	1	0	1	1	1	0.5390625
12	0	0	1	0	1	1	0	0.5312500
13	1	0	1	1	1	1	1	0.5234375
14	1	0	1	1	1	1	0	0.5078125
15	1	1	1	1	1	0	0	0.5000000
16	1	1	1	0	1	1	0	0.5000000
17	1	0	1	0	0	0	0	0.4921875
18	1	0	0	0	1	0	1	0.4921875
19	0	0	0	0	1	1	1	0.4921875
20	0	0	1	0	1	0	1	0.4843750
21	0	1	1	0	1	0	0	0.4687500
22	0	0	1	0	1	1	1	0.4687500
23	0	1	0	0	1	0	0	0.4609375
24	0	0	0	1	1	0	0	0.4609375
25	1	1	0	0	1	0	1	0.4609375
26	1	1	1	1	1	0	1	0.4609375
27	1	0	0	0	1	1	1	0.4609375
28	1	0	0	0	1	0	0	0.4531250
29	1	0	0	0	1	1	0	0.4531250
30	0	1	1	0	1	0	1	0.4531250
31	0	0	1	1	1	0	1	0.4531250
32	0	1	0	0	1	0	1	0.4453125
33	1	0	0	1	1	0	1	0.4453125
34	1	0	0	1	1	0	0	0.4375000
35	0	0	1	1	1	0	0	0.4375000
36	0	1	0	0	1	1	0	0.4375000
37	0	0	0	1	1	1	0	0.4375000
38	0	0	0	0	1	0	0	0.4296875
39	1	1	0	0	1	0	0	0.4296875
40	0	0	0	0	1	1	0	0.4296875
41	0	1	1	0	1	1	0	0.4296875
42	1	1	1	1	1	1	0	0.4296875
43	0	0	0	1	1	0	1	0.4296875
44	0	0	1	1	1	1	1	0.4296875
45	1	1	1	1	1	1	1	0.4296875
46	1	0	1	0	0	1	0	0.4218750
47	1	1	0	0	1	1	0	0.4218750
48	1	0	0	1	1	1	0	0.4218750
49	1	1	0	0	1	1	1	0.4218750
50	1	0	0	0	0	0	0	0.4140625
51	0	1	1	0	1	1	1	0.4140625
52	1	1	1	0	0	0	0	0.4062500

```
## 53      0       0       1       1       1       1       0  0.4062500
## 54      1       0       0       1       1       1       1  0.4062500
## 55      1       0       1       1       0       0       0  0.3984375
## 56      0       1       0       1       1       0       0  0.3984375
## 57      1       0       1       0       0       0       1  0.3984375
## 58      0       0       0       1       1       1       1  0.3984375
## 59      0       1       1       1       1       0       1  0.3906250
## 60      0       1       0       0       1       1       1  0.3906250
## 61      1       1       0       1       1       0       0  0.3750000
## 62      1       1       0       1       1       1       0  0.3750000
## 63      1       1       0       1       1       0       1  0.3750000
## 64      0       1       1       1       1       0       0  0.3593750
## 65      0       1       0       1       1       1       0  0.3593750
## 66      0       1       1       1       1       1       1  0.3593750
## 67      1       1       0       1       1       1       1  0.3515625
## 68      1       0       1       0       0       1       1  0.3437500
## 69      1       1       1       1       0       0       0  0.3281250
## 70      1       1       1       0       0       1       0  0.3281250
## 71      1       0       1       1       0       1       0  0.3281250
## 72      0       1       1       1       1       1       0  0.3281250
## 73      0       1       0       1       1       0       1  0.3281250
## 74      1       0       1       1       0       0       1  0.3203125
## 75      1       0       0       1       0       0       0  0.3046875
## 76      1       1       1       0       0       0       1  0.3046875
## 77      0       1       0       1       1       1       1  0.3046875
## 78      0       0       0       1       0       0       0  0.2968750
## 79      1       0       0       0       0       1       0  0.2968750
## 80      0       1       0       0       0       0       0  0.2890625
## 81      1       1       0       0       0       0       0  0.2890625
## 82      1       1       1       1       0       0       1  0.2890625
## 83      1       1       1       0       0       1       1  0.2734375
## 84      1       0       0       0       0       0       1  0.2656250
## 85      1       0       1       1       0       1       1  0.2656250
## 86      1       1       1       1       0       1       0  0.2578125
## 87      1       0       0       1       0       0       1  0.2265625
## 88      1       1       0       0       0       0       1  0.2187500
## 89      0       0       1       1       0       0       0  0.2109375
## 90      1       1       1       1       0       1       1  0.2109375
## 91      1       1       0       0       0       1       0  0.2031250
## 92      1       0       0       1       0       1       0  0.2031250
## 93      0       1       1       0       0       0       0  0.1718750
## 94      0       1       0       0       0       0       1  0.1640625
## 95      1       1       0       0       0       1       1  0.1640625
## 96      0       0       0       1       0       0       1  0.1562500
## 97      1       0       0       0       0       1       1  0.1562500
## 98      1       0       0       1       0       1       1  0.1562500
## 99      0       1       0       1       0       0       0  0.1484375
## 100     0       1       0       0       0       1       0  0.1484375
## 101     0       0       0       1       0       1       0  0.1484375
## 102     0       0       1       0       0       0       0  0.1406250
## 103     1       1       0       1       0       0       0  0.1406250
## 104     0       0       1       1       0       0       1  0.1328125
## 105     0       1       1       0       0       0       1  0.1250000
## 106     0       1       0       0       0       1       1  0.1250000
```

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## 107   0   0   0   1   0   1   1 0.1250000
## 108   0   1   1   1   0   0   0 0.1093750
## 109   0   0   1   1   0   1   0 0.0937500
## 110   0   1   1   0   0   1   0 0.0859375
## 111   0   0   1   0   0   1   0 0.0781250
## 112   0   1   0   1   0   0   1 0.0781250
## 113   0   0   1   1   0   1   1 0.0781250
## 114   0   1   0   1   0   1   0 0.0703125
## 115   0   1   1   0   0   1   1 0.0703125
## 116   0   1   1   1   0   1   0 0.0625000
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## 118   0   0   1   0   0   0   1 0.0546875
## 119   0   0   1   0   0   1   1 0.0546875
## 120   0   1   0   1   0   1   1 0.0546875
## 121   1   1   0   1   0   1   0 0.0468750
## 122   0   1   1   1   0   1   1 0.0468750
## 123   1   1   0   1   0   0   1 0.0234375
## 124   1   1   0   1   0   1   1 0.0156250
## 125   0   0   0   0   0   1   0 0.0000000
## 126   0   0   0   0   0   0   1 0.0000000
## 127   0   0   0   0   0   1   1 0.0000000
## 128   0   0   0   0   0   0   0        NA
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