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PREVENTING FALLS AND FALLS-RELATED INJURY IN OLDER ADULTS:

A review of New Zealand and international literature

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Health and Ageing Research Team
Massey University
Palmerston North
New Zealand

Hannah Phillips-Wood
h.phillips1@massey.ac.nz

Fiona Alpass
f.m.alpass@massey.ac.nz

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Preventing falls and falls-related injury in older adults: A review of New Zealand and international literature

1 Executive summary

The main purpose of this report is to provide an overview of the risk factors associated with falls in older community-dwelling New Zealanders and to synthesise the evidence related to the effectiveness of interventions to reduce the occurrence of falls and falls-related injury in this population.

1.1 Risk Factors

A literature review was undertaken on risk factors associated with falls and falls-related injuries in older adults/kaumatua. The focus was on studies undertaken after 2010, although articles published before 2010 were included where relevant. Multiple risk factors were identified as associated with increased fall and fall injury risk in older adults. These factors are categorised as person-specific (or intrinsic) and environmental (or extrinsic).

Key findings:

1.1.1 Person-specific / Intrinsic Risk Factors

- Most demographic risk factors are not modifiable but can help to identify likely profiles of individuals with an increased risk of falls who may benefit from targeted falls prevention interventions.
    - The prevalence of falls is significantly higher for those 85 years and older. Older women are more likely to report falling than older men and are more likely to experience a fall injury compared to men. Risk factors associated with falls in this age group differ by gender. Older people with lower SES are at higher risk of experiencing falls.
    - There have been few large representative population studies that have compared risks of falls and falls-related injuries in different ethnic or migrant groups. In New Zealand there is some evidence that older non-Māori are more likely to fall compared to older Māori. It should be acknowledged that this largely reflects a younger age structure of the Māori population (Wren, 2015).
    - There is limited and mixed evidence for differences between rural and urban dwellers and falls incidence. Differences found may be due to the type of outdoor activities undertaken in each geographic location.
- Age-related declines in underlying physiological systems
    - Gait and balance disorders and mobility limitations are among the most common and strongest risk factors for falls and recurrent falls in older adults.
    - Both global measures and specific domains of cognitive impairment (especially executive function) are associated with falls. There is evidence that cognitive

frailty (the presence of both physical frailty and cognitive impairment) predicts falls and recurrent falls.
    - Vision impairment and hearing loss increase the risk of having a fall. Self-perceived hearing handicap may increase the risk of recurrent falls through decreased social participation.
- Behavioural risk factors
    - In general, older adults who participate in physical activity have a decreased risk of falling, and inactive older adults have an increased risk of falling.
    - Alcohol consumption may increase risk of falls although the evidence is mixed. However, older adults' increased sensitivity to alcohol, combined with multiple medications may exacerbate the effects of alcohol on falls risk.
- Medical and health characteristics
    - There is strong evidence for a high incidence of falls and recurrent falls in older adults affected by Parkinson's disease (PD) and stroke. Dizziness and vertigo, cancer, diabetes and particular types of cardiovascular disease and arthritis are also related to falls. Frailty and prefrailty are associated with an increased risk of future falls.
    - Other health characteristics with some evidence for an increased risk of falls include chronic obstructive pulmonary disease, chronic pain and urinary incontinence.
    - One of the most predictive falls-related risk factors is a history of falls.
    - Mixed or limited findings for the relationship between anaemia, malnourishment, excess body weight, foot problems and falls have been reported.
    - Falls are significantly lower among older adults with no chronic conditions compared to those with any chronic condition, and the risk of falls increases with the number of chronic conditions reported.
- Psychological Characteristics
    - Fear of falling has one of the strongest associations with recurrent falls.
    - Higher levels of depressive symptoms are related to a greater likelihood of falling. Poor subjective sleep quality is related to experiencing falls and this relationship may be mediated by depression.
    - There is some limited research on the links between loneliness, social isolation, and an increased risk of falls in older adults. These associations may be moderated by gender and cognitive functioning.
    - There is minimal evidence for the role of falls awareness although this appears to be a protective factor.

1.1.2 Environmental / Extrinsic Risk Factors

- Medications
    - The use of anti-depressants, sedatives or hypnotics, anti-epileptics, opioids and non-steroidal anti-inflammatory drugs (NSAIDS) are all related to falls and falls-injury in older adults.
    - The evidence for the role of cardiovascular medications and falls is mixed. Digitalis, digoxin and loop diuretics may increase the risk of falls, while statins and beta-blocking agents may reduce the risk. Findings for antiarrhythmics and anti-hypertensives are mixed.

    - Polypharmacy is associated with increased risk of falls, recurrent falls, and the risk of hospitalization from falls injury. It is likely that the inclusion of fall-risk inducing drugs contributes to the falls-risk of polypharmacy.
    - There is evidence that withdrawal from or non-adherence of some medications may increase the risk of falls in older adults.
- Hazards in the home, neighbourhood and environment
    - Numerous in-home environmental hazards contribute to falls risk with many related to flooring/carpeting, surfaces and accessibility. Outdoor environmental hazards relate to poorly designed or maintained features of the built environment.
    - Indoor fallers are more likely to be frail with poor health characteristics, while outdoor fallers are more likely to be healthy and active.
    - There is some evidence for the beneficial effects of socially cohesive neighbourhoods on falls risk, particularly for older adults.

1.2 Interventions for Modifiable Risk Factors

A systematic review of the recent literature published after 2010 on interventions targeting modifiable risk factors to prevent falls in older adults/kaumatua was undertaken.

A total of 4,643 papers that addressed interventions targeting modifiable risk factors were identified during the search and, based on the abstract or title, 271 papers were retrieved. Of these papers, 69 measured falls and are included in this review (see Appendix).

Key findings:

1.2.1 Home assessment and modifications

- Home modifications reduce fall rates and are more effective in reducing falls among people who have reported previous falls.
- Checklists, although generic, are among the cheapest and most accessible forms of home assessment, but accuracy depends on the competence of the assessor. Functional home assessments are more comprehensive, time-consuming, and expensive, but better suited for personalised assessments.
- Occupational therapist-led interventions are more likely to lead to a significant reduction in falls, whether a single-component or multicomponent intervention, particularly when the resident is at high risk of falls. The evidence from studies that implement home assessments and modifications without occupational therapists have mixed results but are largely unsuccessful.
- The assessment process should be ongoing, allowing the home to adapt as the person's functionality changes.
- People are reluctant to make changes to their homes, even after learning about the risks.
- Behavioural modifications to address activities of daily living that increase fall risk may be implemented alongside environment modifications to increase effectiveness.

1.2.2 Medication Review

- Gradual cessation of fall-risk inducing drugs is effective in reducing falls, however it may be difficult to implement and sustain medication changes over time.
- Vitamin D may reduce falls in older people who are deficient in vitamin D, but not those with normal levels.

1.2.3 Medical Factors

- Cardiovascular screening is feasible in the context of a multidisciplinary falls prevention strategy, but there is limited evidence for the efficacy of cardiovascular evaluations alone in reducing falls risk. Similarly, there is no reported evidence that hip fracture screening reduces incidence of falls.
- There is strong evidence that exercise is the most cost-effective intervention to prevent falls and recurrent falls in community-dwelling older adults, although the efficacy of exercise interventions in preventing falls varies. Efficacy is increased if interventions include balance and strength training, include high to moderate challenge, be of a sufficient dose to have an effect and be ongoing. Adherence to exercise regimes is often problematic and may not be appropriate or acceptable for some populations of older adults. There is extensive evidence for the effectiveness of the Otago Exercise programme. The evidence for the efficacy of other exercise programmes and those involving technology-based components is minimal in the review timeframe.
- There is an absence of evidence to support the inclusion of power training (high-velocity resistance training) in falls prevention programmes for community-dwelling older adults, although there is support for the efficacy of power training to improve physical function in older frail adults.

1.2.4 Multifactorial and Multicomponent interventions

- Multifactorial approaches, involving an assessment of the fall risk and individualized recommendations for each participant, are strongly supported by the literature, particularly for healthy older adults. Key factors in a multifactorial intervention include using a multidisciplinary team and the introduction of an exercise routine.
- Multifactorial interventions that actively provide interventions tend to be more effective than recommendation-based multifactorial interventions that provide referrals to other services.
- Multicomponent interventions where all participants are subject to the same multiple interventions, rather than being specifically targeted to each participant, should contain an exercise component to be effective.

2 Background

The New Zealand health system, including ACC, is facing increasing demand for services as a result of the ageing population. The number and proportion of the population within the older age stratifications (50 – 59 years, 60 – 69 years, 70 – 79 years, 80 – 89 years, and 90+ years) is going to increase over the next 20 years and by 2034 it is expected that almost a quarter of the population (~1.2M people) will be aged 65 years of age and over. Falls are the most common and costly cause of injury in people 65 years and over. Falls and fractures in people over the age of 65 cost ACC $195m per annum (up 47% on 2013), and the annual cost of claims is growing faster than population growth for this cohort.

In New Zealand there has been little research on the role of ethnicity in falls in older adults. The LILACs longitudinal study found that overall non-Māori were more likely to fall (approximately 40%) at any one time over the 5-year course of the study compared to Māori (approximately 30%). Māori were slightly younger than non-Māori in this study which the authors suggest may partially explain this finding particularly in the latter stages of the study (and ages of the participants). In addition, the rate of falls injuries for kaumātua may be underestimated because of barriers to accessing healthcare services for falls-related injuries (Wren, 2015).

ACC would like to understand the evidence for risk and protective factors associated with falls and falls-related injuries in older adults/kaumātua, as well as the interventions that may mitigate risks or enhance protective factors to prevent falls and falls-related injuries in this population group.

ACC's Injury Prevention Strategy (2018) focuses on delivering sustainable and impactful injury prevention activities, including better understanding root causes and risk factors to better improve investments. This information will be used to inform decision making for investment in services and programmes to prevent falls and falls-related injuries in older adults.

The purpose of this project is to:

- identify and summarise the published, peer-reviewed literature for risk and protective factors related to falls in older people, and
- identify and summarise the interventions which may mitigate risks, or enhance protective factors, to prevent falls and falls-related injuries in older adults.

3 Risk and protective factors for falls and falls-related injuries in older adults/kaumātua

The purpose of the following section is to review the recent literature on risk factors associated with falls and falls-related injuries in older adults/kaumatua. The focus is on studies undertaken after 2010, although articles published before 2010 are included where relevant. Multiple indicators of strength of association between risk factors and outcomes in the literature are reported throughout this review including: odds ratios (OR), relative risk (RR), hazard ratios (HR), incident rate ratios (IRR) and effect sizes (ES). All confidence intervals reported are 95%.

Multiple factors are associated with increased fall and fall injury risk in older adults (Bergen, Stevens, Kakara, & Burns, 2019). The WHO propose a risk factor model for falls in older age with risks categorised into four dimensions: biological, behavioural, environmental and socioeconomic (World Health Organization, 2007). Fall risk factors can also be categorised as person specific (or intrinsic) and environmental (or extrinsic) (Ambrose, Paul, & Hausdorff, 2013). The following review of risk factors combines elements of both classification systems.

3.1 Key findings

This review highlights the multi-factorial nature of falls and the interaction of risk factors that increase the probability of individuals having a fall or experiencing recurrent falls. The research identifies numerous individual risk factors for falls and falls-related injuries, however direct comparisons between studies is hindered by methodological issues. For instance, although this review attempted to focus on community-dwelling older adults, study populations varied in age range, setting and clinical nature. Risk estimates are reported inconsistently with the use of odds ratios (ORs), risk ratios (RR), hazard ratios (HRs) or incident rate ratios (IRR). Unadjusted estimates are often reported. Outcome measures were also varied with falls risk, manifest falls and falls injuries among the outcomes described. Many of the studies are cross-sectional meaning poor evidence of a temporal relationship between risk factors and outcomes, and longitudinal studies have variable follow-up periods. Despite these limitations, there is considerable evidence for the risk associated with a number of person-specific / intrinsic and environmental / extrinsic factors.

Person-specific / intrinsic factors with consistent findings for increased risk of falls in community-dwelling older adults include.

- Advanced age
- Female gender
- History of falls
- Gait & balance problems
- Frailty and muscle weakness
- Poor vision
- Cognitive impairment
- Chronic conditions including Parkinson’s, stroke, cardiovascular disease, arthritis, incontinence, diabetes, depression
- Fear of falling

Extrinsic factors consistently found to be associated with falls in community-dwelling older adults include:

- Medication use, especially psychoactive medications
- Use of assistive devices (improper use)
- Environmental factors, particularly obstacles and tripping hazards and slippery or uneven surfaces

There is some evidence to suggest some risk factors are more important among the old-old and others are important for the young-old. For instance, as described in more detail in the following sections, falls in the home are more likely to be experienced by the frail with poor health characteristics (more prevalent in the old-old), while falls outside the home are more likely to be experienced by the healthy and active e.g., the young-old (Kelsey, Procter-Gray, Hannan, & Li, 2012).

The more risk factors a person has, the greater the chance of them experiencing a fall, multiple falls and falls-related injuries. Given the multifactorial nature of falls risk, prevention, and particularly intervention, should also take a broader approach rather than aiming to change or mitigate one factor at a time. The following section provides a detailed summary of the evidence for person-specific / intrinsic and environmental / extrinsic risk factors.

3.2 Summary of Evidence: Person-specific/Intrinsic Risk Factors

3.2.1 Demographics

Risk factors, such as age, gender and ethnicity are not modifiable, but can help to identify likely profiles of individuals with an increased risk of falls who may benefit from targeted falls prevention interventions.

Age

Falling and fall injuries increase with age due to declines in physiological systems and increases in age-related chronic health conditions (Ambrose et al., 2013). The prevalence of falls is significantly higher for those 85 years and older (Grundstrom, Guse, & Layde, 2012). For instance, a study using nationally representative data from the 2016 US Behavioral Risk Factor Surveillance System examined falls risk factors in a large sample of older adults (65+ years). Falls percentages were significantly higher for those 85 years and older (33.8%, CI 32.1-35.6) compared to younger age groups, 65-74 years (28.7%, CI 28.1-29.4) and 75-84 years (29.0%, CI 28.1-29.9) adjusted for other demographic, geographic, functional and health characteristics (Bergen et al., 2019).

Gender

Research from the United States shows that women are more likely to report falling than men and are more likely to experience a fall injury compared to men (Bergen et al., 2019), however deaths associated with falls are higher for men than women (Ambrose et al., 2013). Data from ACC also show that the proportion of women in New Zealand who lodge claims for falls is greater than for men after the age of 40 (Accident Compensation Corporation, 2018). Analysis of data from 3,112 participants (aged 60+, mean age 71.5 years (SD=9.9)) in the Swedish National Study on Aging and Care in Kungsholmen found more women than men experienced falls resulting in injury (Ek et al., 2019). Different fall risk profiles for men and women over short- and long-term follow-up were also found. In the short-term (<4 years follow-up), risk

factors for injurious falls in women were living alone (HR1.83, CI 1.13-2.96), having 1 or more instrumental activities of daily living (IADL) dependencies (HR 2.59, CI 1.73-3.87), and having had a previous fall (HR 1.71, CI 1.08-2.72). For men the risk factors in the short-term were low systolic blood pressure (HR 1.96, CI 1.04-3.71), previous falls (HR 2.81, CI 1.32-5.97), and impaired strength (HR 3.00, CI 1.52-5.93). For long-term follow-up (4-10 years) the risk factors for women were cognitive impairment (HR 1.49, CI 1.08-2.06), IADL dependency (HR 1.58, CI 1.32-5.97), consuming fall risk–increasing drugs (FRIDs) (1 FRID HR 1.50, CI 1.11- 2.03; ≥2 FRIDs: HR 1.67, CI 1.27-2.20), and being underweight (HR 2.03, CI 1.40-2.95). For men the risk factors at long-term follow-up were impaired balance (HR 1.68, CI 1.08-2.62), current smoking (HR 1.71, CI 1.03-2.84), heart disease (HR 2.20, CI 1.50-3.24), and having had a previous fall (HR 3.61, CI 1.98-6.61). All models were adjusted for age and education.

There is some evidence for a gender impact on the relationship between marital status and risk of falls with unmarried men at risk of falls but not unmarried women (Chang & Do, 2015). The gender differences in the relationship between marriage and health in older adults is well established (Tatangelo, McCabe, Campbell, & Szoeke, 2017). Marital status is clearly linked to living arrangements. A recent systematic review of social isolation, loneliness and falls showed the majority of studies reviewed found that living alone increases the risk of and frequency of falls (Petersen, König, & Hajek, 2020). Older adults living alone are more likely to experience social isolation, loneliness and depression and these factors are in turn associated with chronic health conditions (Kojima, Taniguchi, Kitamura, & Fujiwara, 2020) which may predispose people to falls and falls injury.

Ethnicity

Ethnicity may influence health and health outcomes in many ways (Brown, O'Rand, & Adkins, 2012; Brown, Richardson, Hargrove, & Thomas, 2016). There have been few large representative population studies that have compared risks of falls and falls-related injuries in different ethnic or migrant groups. The Panel on Health and Aging of Singaporean Elderly study examined the effect of ethnicity on falls in the Asian region used longitudinal data from 1,975 participants (mean age 73.6 years (SD=6.2)). The study found that Indians had the highest risk of a future falls followed by Malays, compared to Chinese after adjusting for baseline fall risk factors (T. Y. Chen, Tan, & Chan, 2018). The authors suggest several sociodemographic, cultural and reporting factors may partially account for these differences. Another large population study, The Scottish Health and Ethnicity Linkage Study (SHELS), provides data from the Scottish Census linked to the Scottish Community Health Index with a resulting cohort of 4.62 million people (Cézard et al., 2020). Significant differences were found between white and non-white groups when adjusting for age and socioeconomic status. For instance, there was a 70% higher risk among White Irish males compared to Pakistani males and 40 to 70% higher risk among the White minority females compared with Pakistani and African females. The authors suggest culture, beliefs and behaviours may explain the lower risk of falls for ethnic minorities. In particular, the differential use of alcohol (a known risk factor for falls) between ethnic and cultural groups.

In New Zealand there has been little research on the role of ethnicity in falls in older adults. The LILACs longitudinal study found that overall non-Māori were more likely to fall (approximately 40%) at any one time over the 5-year course of the study compared to Māori (approximately 30%). Māori were slightly younger than non-Māori in this study which the authors suggest may partially explain this finding particularly in the latter stages of the study (and ages of the participants).

Socioeconomic Status

Higher socioeconomic status (SES) is commonly associated with better health among populations and individuals (Marmot, Allen, Bell, Bloomer, & Goldblatt, 2012) and this association is also apparent in older adults (McEniry, Samper-Ternent, Flórez, Pardo, & Cano-Gutierrez, 2019). Recent research has linked SES to falls in this population. Using a large dataset from the Mayo Clinic Biobank, Ryu et al. found a housing-based SES measure was associated with falls risk when adjusted for age, sex, BMI and disease burden (Ryu et al., 2017). Other measures of SES include occupational and educational factors. A secondary analysis from a national government survey of older Koreans found current employment status (adjusted OR 1.24, CI 1.14-1.34) and education level (adjusted OR 1.21, CI 1.10-1.33) to be significant risk factors for falls when controlling for other sociodemographic factors (e.g., gender, age and marital status) (Kim, Choi, & Xiong, 2020). The authors suggest that older people with lower SES are likely to be exposed to environmental hazards to a greater extent and have poorer access to health care services.

Location

Geographical location may also impact on the incidence of outdoor falls in older people. The weather associated with geographic regions is of particular relevance (e.g., ice and snow) (Elvik & Bjørnskau, 2019). Failure to acquire sufficient year-round vitamin D through sun exposure at certain geographical latitudes has increased interest in vitamin D supplementation to prevent falls and fractures. A recent review concluded that the effect of vitamin D supplements on the risk of falls is inconsistent, although vitamin D and calcium supplementation may reduce the risk of fracture (Wu & Pang, 2017).

Rural/urban differences in falls and falls risk factors have also been reported (Moreland, Kakara, & Henry, 2020; L. Zhang, Ding, Qiu, & Li, 2019). Rurality may also determine whether falls result in hospitalisation. For instance, one New Zealand study used Statistics New Zealand's integrated data infrastructure (IDI) to examine the relationship between rurality and unintentional non-fatal hospitalisations for falls in Northland and Auckland regions (Zhao et al., 2020). The odds of being hospitalised from a fall were found to be lower among those who lived in rural areas. In contrast, a recent study examining GPS data from ambulances attending falls occurring on the road or footpath in New Zealand found that those who fell in rural areas were more likely to be taken to hospital following a fall (Watkins et al., 2020). Differences between rural and urban falls incidence may be due to the type of outdoor activities undertaken in each geographic location.

3.2.2 Systems

During normal ageing physiological changes occur to underlying systems including sensory systems, the cognitive system, and the musculoskeletal system. Declines in these systems have been shown to increase the risk of falls.

Gait and Balance

Gait and balance disorders increase markedly with age and are among the most common and strongest risk factors for falls in older adults (Cuevas-Trisan, 2017; Salzman, 2010). Gait disorders, and associated balance issues, can be the result of neurological or psychiatric conditions, orthopaedic problems and medical conditions, and may have several aetiologies in older adults (Pirker & Katzenschlager, 2017). A 2010 systematic review and meta-analysis of risk factors for falls found a strong association between gait problems and falls (OR 2.02, CI 1.39-2.93) and recurrent falls (OR 2.58, CI 1.79-3.74) (Deandrea et al., 2010). Another

systematic review and meta-analysis found balance deficits associated with increased risk of falls in community-dwelling older adults (RR 1.42 (CI 1.08 – 1.85) and OR 1.98 (CI 1.60-2.46) (S.W. Muir, Berg, Chesworth, Klar, & Speechley, 2010). The authors note that these associations are less than had been previously published and attribute the smaller values to the exclusion of institutionalised populations in their review. Recent New Zealand research from the LILACS study found slower gait speed was predictive of falls over 5 years. For non-Māori a slow gait speed significantly increased the odds of falling (OR 0.40, CI 0.24–0.68), though this was not the case for Māori (Lord et al., 2020).

Mobility

Mobility limitations (including changes in gait) are strongly related to negative health outcomes including risk of falls (Musich, Wang, Ruiz, Hawkins, & Wicker, 2018). A prospective cohort study investigated the prevalence and distribution of 8 modifiable risk factors in 1,077 patients aged 65+ (mean age 78.5 years (SD=7.8)) presenting after a fall at an A&E department in Amsterdam (van Nieuwenhuizen et al., 2010). Balance and mobility disorder was the most prevalent risk factor present in 69.3% of patients and was independently associated with recurrent falls in multivariate logistic regression (OR 1.9, CI 1.1-3.3).

Mobility limitations are often defined as reported difficulty walking or climbing stairs. A case-control study in an Accident Service Unit in Sri Lanka investigated risk factors for domestic falls for 200 older adults (60+ years). Difficulty in walking was an unadjusted significant risk factor (OR 2.20, CI 1.09-4.44) for falls in the home (Prathapan et al., 2017).

Functional mobility may be measured in numerous ways. Taylor et al. (2014) explored the relationship between physical and functional mobility and falls in 174 individuals (mean age 82.2 years, range 62-98) living in the community or at a low-level care facility with mild to moderate cognitive impairment (Taylor et al., 2014) . Falls were measured using monthly falls calendars prospectively over 12 months. A number of measures of functional mobility were related to falls in univariate analyses including: co-ordinated stability (IRR 1.597, CI 1.321-1.932); timed-up-and-go (IRR 1.400, CI 1.132-1.731); sit-to-stand (IRR 1.559, CI 1.282-1.896) and gait velocity (IRR 0.779, CI 0.627-0.961). Co-ordinated stability was related to falls when controlling for age education and cognitive function (IRR 1.79, CI 1.16-2.75).

Mobility limitations may influence falls through an interaction with physical activity. A prospective cohort of 700 men (mean age 78.0 years (SD=4.5)) from the British Regional Heart Study compared those with mobility limitations (difficulties in getting about outdoors) to those without mobility limitations (Jefferis et al., 2015) and found that for men with mobility limitations falls risk declined with increased physical activity, but for those without limitations falls risk increased with increased physical activity. The authors suggest that highly active men may perform beyond their abilities whereas men with mobility limitations are more aware of and adapt their activities to their limitations.

Early signs of mobility decline may predict future falls. As part of the Finnish Twin Study on Aging (FITSA), Manty et al. examined whether self-reported preclinical mobility limitation predicted future falls (Manty et al., 2010). Preclinical mobility is defined as a stage between normal functioning and evidence of distinct mobility limitation. The participants were 428 community-living women (aged 63 to 76 years). Among women without previous fall history, preclinical and established mobility limitation did not predict future falls, however for those who had fallen in the past year, preclinical mobility limitation (IRR 3.77, CI 1.02-13.92) and manifest mobility limitation (IRR 14.66, CI 2.72-79.00) increased the adjusted risk of future falls compared to individuals with no mobility limitations and no previous falls.

Cognitive Function

Cognitive impairment and dementia have been identified as independent risk factors for falls in older adults (Campbell et al., 2019; S. W. Muir, Gopaul, & Montero Odasso, 2012). Global measures of cognitive impairment have been associated with falls. In a sample of 765 community-dwelling participants aged 70+ in the MOBILIZE Boston Study, cognitive performance (as measured by the MMSE) predicted an increasing falls trajectory over a five year study period (Tchalla et al., 2014).

Specific domains of cognitive function, such as executive function, have also been the focus of a number of studies. A systematic review examining the association between measures of executive function and falls (studies from 1991 to 2011) found 9 out of 10 studies where falls was the primary outcome reported an association with executive function (Kearney, Harwood, Gladman, Lincoln, & Masud, 2013). A cross-sectional study of 4,481 community-dwelling older adults (aged 65 to 97 years) in France found impaired executive function was significantly associated with any fall (RR 1.13, CI 1.03-1.25), and soft tissue fall injury (RR 2.42, CI 1.47-4.00) when adjusted for age, sex, number of medications, fear of falling and depression but not to recurrent falls or fall injury involving fracture (S. W. Muir et al., 2013) . An Australian study of 215 participants from the population-based Tasmanian Study of Cognition and Gait (aged 60 to 85 years) found no significant associations between composite cognitive scores and risk of single falls (Martin et al., 2013). Although overall executive function scores were not associated with risk of multiple falls, three component tests of executive function (Stroop dot subtest, Stroop words subtest and category fluency) were, although relative risk ratios were small.

Focusing on both global and specific cognitive domains is important given that declines in cognitive function do not occur uniformly across domains (Cloutier, Chertkow, Kergoat, Gauthier, & Belleville, 2015) and examining patterns of cognitive decline may help in identifying antecedents of falls. The Cardiovascular Health Study, a large longitudinal population study with 15-year follow-up was used to examine the influence of decreased global cognitive function, processing speed or both on the increased risk of serious falls requiring hospitalization in 5,356 older adults (65+ years) (Welmerink, Longstreth, Lyles, & Fitzpatrick, 2010). The study found poorer processing speed was related to a higher risk of hospitalisation for a serious fall when adjusting for covariates in a time-dependent model. For global cognition, the risk of a serious fall resulting in hospitalization was weaker and differed for those with cardiovascular disease (CHD) and those who didn't. Decreased cognition was not a risk factor for those with CHD. Smith et al. investigated the relationship between falls and specific cognitive domains in a sample of 5197 participants from the English Longitudinal Study of Ageing (mean age 69.6 years (SD=7.8)) (Smith et al., 2019). Three domains of cognitive function were assessed: memory, executive function and numeracy. None of the six cognitive function measures were associated with falls in the past 12 months when adjusted for demographics and comorbidities. For recurrent falls (two or more falls in the previous 12 months) two cognitive function parameters remained significant after adjustment. Individuals who scored higher on orientation (in time) were significantly less likely to experience recurrent falls (OR 0.80, CI 0.65-0.98) and those with better verbal fluency were significantly less likely to experience recurrent falls (OR 0.98, CI 0.96-1.00). Taylor et al. explored the relationship between cognitive domains and falls in 177 individuals (60+ years, mean 82.2 years (SD=6.8)) living in the community or at a low-level care facility with mild to moderate cognitive impairment (Taylor et al., 2017). Global cognition, memory and language were not associated with multiple falls when controlling for age, sex and education. However, the authors found that the specific domains of executive function (RR 1.50, CI 1.18-1.91), processing speed (RR 1.24, CI 1.06-1.46), and visual spatial ability (RR 1.18, C 1.01-1.37), were significantly

associated with multiple falls when adjusted for confounds. Poor executive function increased the risk of falls by 50%.

There is some evidence that cognitive decline may be an early signal for falls risk. Using data from 2,495 participants (60+ years, mean 72.0 years (SD=9.8)) from the Swedish National Study on Aging and Care in Kungsholmen, Welmer and colleagues (Welmer, Rizzuto, Laukka, Johnell, & Fratiglioni, 2017) found poorer baseline processing speed and executive function, were significantly associated with increased risk of injurious falls over longer periods of follow-up (5 and 10 years) but not shorter time periods (3-year follow-up). Analysing data stratified by global cognitive function showed processing speed and executive function were only associated with injurious falls in participants without cognitive impairment at follow-up. Conversely there is also evidence that falls risk predicts later cognitive decline. Using the National Health and Aging Trends Study (NHATS) Crow et al. undertook a secondary analysis using a sample of 7,146 older adults (aged ≥65 years) to investigate whether those at higher risk of falls had higher rates of cognitive impairment at 8 year follow-up (Crow et al., 2021). Older adults with normal baseline cognitive functioning who were categorised as having a high fall risk were found to have a 74% higher risk of developing cognitive impairment compared to low falls risk participants over 8 years.

The concept of *cognitive frailty* has been the subject of recent research. Cognitive frailty refers to the presence of both physical frailty and cognitive impairment. A cross-sectional observational study of 10,202 (65-96 years, mean age 73.6 (SD=5.5)) community-dwelling older adults registered in the National Center for Geriatrics and Gerontology – Study of Geriatric Syndromes in Japan found older adults with cognitive impairment had a higher rate of falls (OR 1.23, CI 1.04-1.45) when adjusted for demographics, medications, and comorbidities (Tsutsumimoto et al., 2018). In addition, those participants with cognitive frailty had high rates of falls (adjusted OR 1.46, CI 1.23-1.73) and falls-related fractures (adjusted OR 1.92, CI 1.20-3.08). A more recent longitudinal study examined whether baseline cognitive frailty predicted falls at 3-year follow-up (Y. Ma et al., 2021) . Using data from the Rugao Longevity and Aging Study in China, (N=965 participants (mean age 75.2 years (SD=3.9)), the study found that cognitive frailty was associated with falls at baseline (OR 3.51, CI 1.18-10.44) and falls at 3-year follow-up (OR 3.41, CI 1.11-10.50) when adjusted for confounds. Similarly, the New Zealand LILACs longitudinal study investigated how cognitive and physical functioning were associated with fall risk (Lord et al., 2020). They found subjective cognitive impairment was significantly associated with falls (OR 1.65, CI 1.07–2.55) in older non-Māori but when combined with gait speed (Motoric Cognitive Risk (MCR) Syndrome) individuals were nearly two and a half times more likely to fall than those without MCR (OR 2.45, CI 1.06–5.68). Motoric cognitive risk syndrome is defined as a "pre-dementia syndrome" and is highly predictive of future risk of dementia (Crow et al., 2021).

Vision and Hearing

The prevalence of vision and hearing impairment increases with age. Sensory impairments are thought to impair balance, and vision and hearing ability are crucial in maintaining postural control (Gopinath, McMahon, Burlutsky, & Mitchell, 2016), thus sensory deficits increase the risk of falls. For instance, analysis of data from two large cohorts of older Australians found that vision impairment was associated with increased risk of having a fall in men and women (77% and 82% increased risk respectively) as was hearing impairment (men 38% increased risk and women 45% increased risk) (Lopez et al., 2011). Vision impairment was also associated with being injured from a fall in both men (69% increased risk) and women (79% increased risk).

Vision loss is a significant cause of disability in older New Zealanders (Statistics New Zealand, 2013). Specific types of vision impairment, including cataracts (Ho, Hong, Thang, Ong, & Koh, 2020; Mitchell-Fearon et al., 2014; Prathapan et al., 2017), glaucoma (Bhorade et al., 2021), presbyopia (and the use of multifocal corrective lenses) (Reed-Jones et al., 2013) and macular degeneration (Wood et al., 2011) have been shown to increase the risk of falls. Self-reports of vision impairment have also been related to falls risk. For instance, Ehrlich et al. used data from the National Health and Aging Trends Study (NHATS), a nationally representative cohort of Medicare beneficiaries aged 65 and older (N=11,558), to examine the association between self-reported hearing impairment and falls outcomes (Ehrlich, Hassan, & Stagg, 2019). After adjusting for age, sex, and other covariates, they found prevalence estimates for falls in the past month were significantly higher for those with self-reported vision impairment 14.5% (CI 13.1–16.0) than those without 10.5% (CI 10.0–10.9) For recurrent falls the difference between the two groups was even greater: 13.5% (adjusted, CI 13.0–14.0) for those without vision impairment and 20.6% (adjusted, CI 18.5–22.8) for those with vision impairment.

Hearing loss is highly prevalent in older adults but is severely undertreated (A. N. Simpson, Matthews, Cassarly, & Dubno, 2019), suggesting a potentially easily modifiable falls risk target. A systematic review and meta-analysis found that older adults with hearing loss had greater odds of falling compared to those without hearing loss (OR 2.39, CI 2.11-2.68) (Jiam, Li, & Agrawal, 2016). While the mechanisms for the impact of impaired vision on the risk of falls are clear, hearing impairment may operate through less obvious pathways such as vestibular disfunction, poor auditory awareness or increases in cognitive load needed to listen (important for walking and navigating the environment) (Lin & Ferrucci, 2012). In addition, hearing loss has been found to be related to poorer access to healthcare services for older adults (Pandhi, Schumacher, Barnett, & Smith, 2011) which may result in subsequent poorer health and a higher risk of falls.

Not only is there an association between formally measured hearing impairment and risk of falls but the emotional distress and social and communication problems experienced by the hearing impaired (hearing handicap) have also been found to be related to falls in older adults. Utilising data from 1,478 participants (aged 55+) in the Blue Mountains Eye Study, a population-based cohort study, Gopinath et al. found objective measures of hearing impairment were unrelated to the incidence of falls (Gopinath et al., 2016). However, participants with significant self-perceived hearing handicap were significantly more likely to experience 2 or more falls over the 5-year study period (adjusted OR 1.93, CI 1.02-3.64) compared to those with no hearing handicap. The authors suggest one explanation for this finding is that those with severe hearing handicap may reduce their participation in everyday activities leading to further disablement and increase in fall risk.

3.2.3 Behavioural

Behavioural risk factors include those related to actions, emotions and daily activities and are potentially modifiable (Ambrose et al., 2013).

Physical Activity/Sedentariness

Physical activity is considered one of the main protective factors for falls in older adults (Lesley D Gillespie et al., 2012) while sedentary behaviour is seen as a detrimental factor (Bull et al., 2020). An early systematic review and meta-analysis found that physical activity in older adults was associated with a reduced risk of falling (OR 0.75, CI 0.64-0.88) and for those who were physically inactive or sedentary falls risk increased (OR 1.41, CI 1.10-1.82) (Thibaud et al.,

2012). A more recent meta-analysis of 10 prospective cohort studies (N=58,241, aged 65+ years) found that older adults who participated in physical activity had a decreased risk of falling (RR 0.976, CI 0.957-0.996), and inactive older adults had an increased risk of falling (RR 1.082, CI 1.007-1.163).

Alcohol Consumption

Alcohol consumption may increase the risk of falls due to its effects on balance, cognition and risk-taking behaviour (Szabó, Towers, Sheridan, & Newcombe, 2021). Older adults have increased sensitivity to alcohol due to physiological changes related to ageing, and have a higher prevalence of comorbidities, including those related to gait, balance and vision (Ortolá et al., 2017). Older adults are also more likely to be on multiple medications, many of which may exacerbate the effects of alcohol (Holton et al., 2019). A retrospective cross-sectional study of just over 89,000 InterRAI assessment records of community-dwelling older adults in Hong Kong examined risk factors for falls from four domains from the WHO's Risk Factor Model for Falls (Qian et al., 2021). Of the 37 significant risk factors alcohol consumption had the second highest odds ratio (OR 1.90, CI 1.47-2.61), after functional status. However, other studies which have examined alcohol use as a risk factor for falls in community-dwelling older adults have reporting conflicting findings. In a literature review of medication and alcohol use as risk factors for falls in older adults, only five of the fifteen studies examined reported an association between falls and alcohol consumption (Laberge & Crizzle, 2019). Patterns of alcohol consumption may explain differing findings. A prospective study of community dwelling older adults in Spain found that compared with never drinkers, moderate drinkers showed a significantly lower risk of recurrent falls (≥2) (OR 0.58, CI 0.38–0.88) and of falls necessitating medical care (OR 0.67, CI 0.46–0.96) (Ortolá et al., 2017). Moderate drinkers with a preference for wine and drinking only with meals ("Mediterranean drinking pattern") showed a lower risk of ≥1 fall (OR 0.73, CI 0.54–0.99), of ≥2 falls (OR 0.56, CI 0.34–0.93), and of falls requiring medical care (OR 0.61, CI 0.39–0.96) than non-drinkers. There was no association between heavy drinking and falls, recurrent falls or falls requiring hospital treatment. Another large prospective study also found a U-shaped relationship between alcohol consumption and falls over a median follow-up of 11.5 years (Tan et al., 2021). The cumulative incidence of hospitalised falls for non-users was 11.08% (9.94–12.35) and for heavy users 8.20% (6.35–10.56), higher than for light users 7.53% (7.02–8.08) and moderate users 5.91% (5.29–6.59).

3.2.4 Medical and Health Characteristics

Multiple medical and health characteristics feature in systematic reviews of risk factors for falls in older adults. For instance, Deandrea et al.'s systematic review and meta-analysis highlights the role of a number of medical factors in falls risk (Deandrea et al., 2010). The strongest associations for recurrent fallers were for Parkinson's (2.84, CI 1.77-4.58), dizziness and vertigo (OR 2.28, CI 1.90-2.75), and history of stroke (OR 1.79, CI 1.51-2.13). Similar but weaker associations were found for all fallers. Urinary incontinence, rheumatic disease, hypotension and diabetes also showed significant links to both fallers and recurrent fallers.

A secondary data analysis using the Behavioral Risk Factor Surveillance System (BRFSS) survey investigated the prevalence of falls, recurrent falls and chronic health conditions in a sample of 159,336 community-dwelling older adults (65+ years) (Paliwal, Slattum, & Ratliff, 2017). The BRFSS is a large cross-sectional US population-based survey. Significant positive associations were found between falls and cancer (OR 1.13, CI 1.06-1.20), angina (OR 1.17, CI 1.09-1.27), asthma (OR 1.22, CI 1.13-1.32), chronic kidney condition (OR 1.27, CI 1.14-1.42), diabetes (OR 1.32, CI 1.24-1.40), stroke (OR 1.61, CI 1.46-1.76), arthritis (OR 1.61, CI

1.52-1.70) and depression (OR 2.26, CI 2.11-2.42) while controlling for other sociodemographic and behavioural factors. Several factors were predictive of both first-time falling and recurrent falling (stroke, chronic kidney condition, arthritis, depression and diabetes) while others predicted recurrent falling after experiencing a first fall (heart attack, angina, asthma, COPD).

Gale et al. found health factors that predicted falls differed by gender over a four-year period (Gale, Westbury, Cooper, & Dennison, 2018). Using data from 3,298 core participants aged 60+ from the English Longitudinal Study of Ageing they found that higher levels of pain (RR 1.10, CI 1.04-1.17) and poorer balance (RR 1.23, CI 1.04-1.47) were associated with increased risk of falls in men, while depression (RR 1.03, CI 1.01-1.06) and incontinence (RR 1.12, CI 1.00-1.24) were associated with an increased risk in women.

A number of these risk factors are addressed in more detail in the following sections.

Parkinson's Disease

The incidence of falls and recurrent falls in those affected by Parkinson's disease (PD) is very high in older adults (Allen, Schwarzel, & Canning, 2013; Fasano, Canning, Hausdorff, Lord, & Rochester, 2017). There are multiple PD-specific fall risk factors. For instance, Creaby et al. in a systematic review and meta-analysis highlight a number of gait characteristics associated with falls in Parkinson's disease including walking speed, lower cadence and shorter strides (Creaby & Cole, 2018). An earlier systematic review identified a number of factors associated with prospectively recorded recurrent falls in PD, including disease severity, motor impairment, treatment with dopamine agonists, increased levodopa dosage, cognitive impairment, freezing of gait, impaired mobility, fear of falling, fall history and reduced physical activity (Allen et al., 2013).

Older adults without PD may also exhibit Parkinson's signs (PS). These signs are similar but milder than those seen in PD but may also be associated with falls risk. A longitudinal study drawn from the Philadelphia Healthy Brain Aging (PHBA) cohort investigated the role of PS on the risk of falls among a sample of 1,100 community-dwelling older adults (mean age 68.2 years (SD=8.8)) without previously diagnosed Parkinson's disease or dementia (Dahodwala, Nwadiogbu, Fitts, Partridge, & Karlawish, 2017). After controlling for demographics and clinical fall risk factors, older adults with PS were 38% more likely to fall than those without PS (RR 1.38, CI 1.04–1.82) and were significantly more likely to be injured during the fall.

Frailty

Frailty is conceptually defined as "a clinically recognizable state in which the ability of older people to cope with everyday or acute stressors is compromised by an increased vulnerability brought by age-associated declines in physiological reserve and function across multiple organ systems" (pg.viii) (World Health Organization, 2017). A 2015 meta-analysis found frailty (OR 1.84, CI 1.43–2.38), and prefrailty (OR 1.25, CI 1.01-1.53), were significantly associated with an increased risk of future falls among community-dwelling older people (Kojima, 2015). A recent prospective cohort study with a 4-year follow-up investigated the relationships between physical frailty, fear of falling and future falls in 2,469 Japanese community-dwelling adults aged 65+ (mean age 71.1 years (SD=4.7)) (Makino et al., 2021). Prefrailty or frailty increased the risk of future falls (OR 1.55, CI 1.19-2.02) when adjusting for age, sex and multiple falls risk factors including fear of falling. Similar findings were reported from data obtained from the China Health and Retirement Longitudinal Study (N=4,349, 60+ years, mean age 67.1 (SD=6.0)) (Q. Zhang, Zhao, Liu, & Ding, 2020). Frail participants were at increased risk of falls at 4-year follow-up (OR 1.54, CI 1.14–2.08) after adjustment for multiple confounds. Prefrailty was also predictive of falls after similar adjustment (OR 1.24, CI 1.05-

1.47). Hayashi et al. examined the interaction of physical frailty (PF) and social isolation (SI) on falls in 380 community-dwelling older adults in Japan (mean age 72.3 (4.6) years) (Hayashi et al., 2020). Results showed that participants categorised as PF or SI were not at higher risk of falls than the reference group ("robust" participants). However, the participants categorised as *both* PF and SI were at higher risk of falling compared with the robust group (OR 3.06, CI 1.00– 9.34) after controlling for multiple confounding factors.

Dizziness and Vertigo

Dizziness is a frequent occurrence among older adults and its prevalence increases with age (de Moraes et al., 2011). An early systematic review and meta-analysis of falls risk factors found dizziness and vertigo to be related to all falls (OR 1.80, CI 1.39-2.33) and recurrent falls (OR 2.28, CI 1.90-2.75) (Deandrea et al., 2010)). Benign paroxysmal positional vertigo (BPPV) is the most common cause of dizziness (Lindell et al., 2021). As part of the population-based Gothenburg H70 birth cohort studies in Sweden, 671 older adults (75+) were categorized into three groups: (i) participants with BPPV, (ii) participants reporting having problems with dizziness/impaired balance, and (iii) participants without problems with dizziness. Dizziness (both BPPV and general dizziness) was related to a higher number of falls over the previous year (Lindell et al., 2021).

Chronic Obstructive Pulmonary Disease

Compared to healthy community-dwelling older adults, people with chronic obstructive pulmonary disease (COPD) experience a higher prevalence of falls (Hakamy, Bolton, Gibson, & McKeever, 2018). This increased risk is thought to be due to a combination of common risk factors in older adults and COPD disease related factors such as breathlessness, muscle weakness, limited mobility and decreased physical activity (Birinci, Kısa, Akıncı, Kuran Aslan, & Kıyan, 2021; Oliveira et al., 2015). A recent systematic review and meta-analysis examined and integrated the falls outcomes and risk factors reported in twenty-three studies in COPD (Oliveira et al., 2020). The pooled prevalence of COPD fallers was 30% (CI 19%–42%), and the pooled prevalence of frequent fallers (≥2 falls) was 24% (CI 2%–56%). The authors note the varying study methodologies used across the studies reported. Examining the risk factors for falls in those with stable COPD, common risk factors for older adults were identified (e.g., age, female gender, falls history, the number of medications, coronary heart disease comorbidities, impaired balance performance) as well as more disease-specific factors such as use of supplemental oxygen and smoking history.

Stroke

Falls are commonly reported after stroke and occur in up to 58% of people one year post stroke (Xu et al., 2018). A 2010 systematic review and meta-analysis of risk factors for falls in community-dwelling older adults found one of the strongest associations for recurrent fallers was history of stroke (OR 1.79, CI 1.51-2.13) (Deandrea et al., 2010). A 2011 prospective study compared rates of falls between individuals recently discharged from stroke rehabilitation (N=80) and age and gender matched controls (N=80) (L. A. Simpson, Miller, & Eng, 2011). Individuals with stroke were found to fall more often than the matched controls over a period of 13 months (IRR 1.767, CI 1.149-2.716).

There is evidence that markers of cerebral small vessel disease (and risk factors for stroke) are also associated with falls risk. Callisaya et al. pooled data from two Australian population-based studies (Tasmanian Study of Cognition and Gait and Sydney Memory and Ageing Study) (Callisaya et al., 2014). In a sample of 655 older adults (mean age 75.5 years (SD=6.7)) they found an increased risk of multiple falls in those with three or more sub-cortical infarcts (SIs)

(RR 1.89, CI 1.03-3.46) and for those with the highest white matter hyperintensity volume (RR 1.46, CI 1.00-2.13) adjusted for potential confounds.

Cancer

Older adults with cancer have an increased risk of falls (adjusted OR 1.17, CI 1.04-1.32), compared to individuals without a cancer diagnosis in this age group (Mohile et al., 2011). The disease process itself may increase the risk of falls through impaired physical function, strength and mobility (Schroder Sattar, Alibhai, Spoelstra, Fazelzad, & Puts, 2016). In addition, cancer treatments may also increase falls risk e.g., chemotherapy-related neuropathy, anaemia and pain medication (Wildes et al., 2015). A recent systematic review of the literature on falls in older adults with cancer concluded that falls in this group are common, result in a high rate of injury, and "appear to affect cancer treatment and possibly disease trajectory and outcomes" (pg.30) (S Sattar et al., 2021). The authors note that more research is needed on predictors and impacts of falls in older adults with a diagnosis of cancer.

Cardiovascular Disease

The incidence of cardiovascular disease increases with age and many cardiovascular conditions have been found to be associated with falls (Mikos, 2021).

Orthostatic hypotension (OH) or postural hypotension is associated with dizziness and syncope. A 2019 systematic review and meta-analysis examined the relationships between OH and falls in various populations of older adults (65+ age) (Mol et al., 2019). Fifty studies from 1946 to 2017 were included in the meta-analysis which found that overall OH was significantly related to falls (OR 1.73, CI 1.50-1.99) and this finding was independent of study population, design quality, OH definition and blood pressure measurement method. Subgroup analysis by study population found the highest OR was for patients with Parkinson's disease (OR 2.30, CI 1.53-3.48). Studies which included populations of community-dwelling older adults produced an OR of 1.50 (CI 1.15-1.97).

There is conflicting evidence for the association between blood-pressure patterns and the risk of falls (Bladh, Nilsson, Carlsson, & Lexell, 2013). Jonas et al. investigated whether blood-pressure patterns, as measured by 24-hour ambulatory blood pressure monitoring was associated with fall injuries in hypertensive older adults (70 years+) at 1-year follow-up (Jonas, Kazarski, & Chernin, 2018). Low diastolic blood pressure was related to fall-injury events (OR 0.92, CI 0.89-0.96) after adjusting for covariates. Gender may play a role in how blood pressure patterns are associated with falls risk. Data from the Austrian Vorarlberg Health Monitoring and Prevention Programme was used to examine the relationship between blood pressure and falls in 3,500+ community-dwelling people aged 60+ years (Klein et al., 2013). The authors found a decreased risk of falls in women with hypertensive values for either systolic (OR 0.91, CI 0.84-0.98) or diastolic (OR 0.92, CI 0.85-0.99) blood pressure and an increased risk of falls in men with low systolic (OR 2.46, CI 1.10-5.54) and diastolic blood pressure (OR 1.77, CI 1.02-3.07) when adjusting for covariates including age, and number of medical conditions.

Atrial fibrillation (AF), another cardiovascular condition where prevalence increases with age, is also associated with increased falls risk. A recent systematic review and meta-analysis of 7 studies with over 36,000 older adults (mean age 72 years (SD=10)) found that AF was independently associated with falls (OR 1.19, CI 1.07-1.33) (Malik et al., 2020). One of those studies included in the meta-analysis used data derived from the records of 14,056 cardiovascular patients in Tokyo (Arita et al., 2019). The study population was grouped by age (younger: <75 years of age and older: ≥75 years of age) and according to baseline cardiac rhythm (sinus rhythm (SR), paroxysmal AF (PAF), and persistent AF (PeAF)). In the younger

group neither PAF or PeAF were associated with falls in multivariate models, however for the older group, PeAF was significantly associated with risk of falls (HR 2.20, CI 1.15-4.07).

Diabetes

Diabetes mellitus is associated with an increased risk of falling. A systematic review and meta-analysis of six prospective cohort studies of older adults (60+ years) found diabetes was associated with an increased risk of falls (RR 1.64, CI 1.27-2.11) compared to healthy controls (Y. Yang, Hu, Zhang, & Zou, 2016). Insulin-treated patients had a greater risk of falls (RR 1.94, CI 1.42-2.63) compared to those not treated with insulin. Similar results were found using longitudinal data from the Health, Aging, and Body Composition (Health ABC) Study (Yau et al., 2013). Yau et al. examined whether older adults with diabetes, with or without insulin therapy, were more likely than those without diabetes to have a fall requiring hospitalisation. Older adults with diabetes had a higher risk of a hospitalised falls injury compared to those without diabetes (HR 1.41, CI 1.05–1.88) after adjusting for potential confounds. Using insulin was related to an increased risk of hospitalisation due to falls injury compared to those without diabetes (HR 3.00, CI 1.78–5.07) and those with diabetes not using insulin (HR 2.18, CI 1.22–3.93).

Falls in diabetic individuals may be due in part to sensory declines associated with peripheral neuropathy and retinopathy (Yau et al., 2013) and cognitive function (Blackwood, 2019). Hypoglycemia may also contribute to falls and falls injury. In a study utilising healthcare claims for individuals with employer-sponsored Medicare supplemental insurance, older adult patients (65+ years) with hypoglycemic events had 45–70% higher odds of falls-related fractures than patients without hypoglycaemic events when adjusted for disease-related confounding factors (S. Johnston, Conner, Aagren, Ruiz, & Bouchard, 2012).

Pain

Two systematic reviews and meta-analyses have shown that chronic pain is associated with falls and recurrent falls in community-dwelling older adults (Stubbs, Binnekade, et al., 2014; Stubbs, Schofield, et al., 2014). In the later meta-analysis older adults with pain were three times as likely to experience recurrent falls compared to those without pain (OR 3.05, CI 1.75–5.31). A recent population-based cohort study found a significant association between chronic pain and risk of injuries in 765 participants aged 70+ (mean age 78.1 years (SD=5.4)) (Cai, Leveille, Shi, Chen, & You, 2020). Participants with the highest “pain interference” (with activities and mood) had a 61% greater risk of injurious falls at 4-year follow-up compared to those with the lowest “pain interference” (RR 1.61, CI 1.23-2.13) adjusted for multiple fall risk factors and sociodemographic characteristics. Multisite pain was also associated with increased risk of injurious falls (adj. RR 1.57, CI 1.22-2.01). Pain severity was not associated with an increased risk for falls resulting in injury initially after adjustment. In the short-term, monthly pain severity ratings were associated with injurious falls in the subsequent month. Those who reported bodily pain as “severe” or “very severe” had a 61% greater risk of injurious falls in the subsequent month compared to those reporting no pain (OR 1.61, CI 1.12-2.31) adjusted for multiple risk factors. Li et al. examined the relationship between falls and pain, insomnia and depressive symptoms with 2,558 community-dwelling older adults (65+) from the National Health and Aging Trends Study (NHATS). Older adults with pain had higher rates of falls (OR 1.36, CI 1.23–1.50) after adjusting for covariates. This association remained after adjustment for insomnia and depressive symptoms (OR 1.36, 1.22–1.51).

Anaemia

Anaemia is common in older adults and the prevalence increases with age (Katsumi, Abe, Tamura, & Matsushita, 2021). Symptoms can include low energy, fatigue, dizziness, and

general weakness, all potential falls risk factors. The research findings for the relationship between anaemia and falls are mixed. Thaler-Kall et al. found no significant association between anaemia and falls in an analysis of data from 967 community-dwelling people aged 65+ years from the KORA-Age study (Thaler-Kall et al., 2014). However, they did find a 2-fold increase in risk for participants with anaemia *and* disability compared to those without anaemia and disability (OR 2.10, CI 1.12-3.93) after adjustment for age, sex and number of drugs. Hopstock et al., used data from the population-based Tromsø study (2441 participants aged 65+) to replicate the KORA-Age study (Hopstock, Utne, Horsch, & Skjelbakken, 2017). No statistically significant associations were found between measured anaemia or hemoglobin and self-reported falls, or with combinations of anaemia and frailty or disability, and falls. The authors note that both these studies differ from earlier studies that found consistent associations between anaemia and falls and suggest variations in methodology may account for these differences.

Weight

Excess body weight is considered a fall risk factor (Mitchell, Lord, Harvey, & Close, 2014). Using data from the longitudinal Health and Retirement panel study Cho et al. examined the association between BMI and central obesity and falls in 3,383 older adults aged 65+ (Cho, Seo, Lin, Lohrmann, & Chomistek, 2018). Although no relationship between BMI and falls was found, obese individuals were less likely to experience a *fall injury* than normal weight individuals (adjusted OR 0.56, CI 0.35-0.91). This relationship with falls injury was not found for individuals with central obesity and the authors suggest that distribution of weight may be more important than weight alone when examining the relationships with falls. Older adults with central obesity were more likely to fall (OR 1.37, CI 1.01-1.85) and experience recurrent falls (IRR 1.15, CI 1.03-1.29) than those without central obesity. The authors also found that normal weight older adults with central obesity had a higher fall incidence than obese older adults without central obesity. The 2019 systematic review and meta-analysis by Trevisan et al. found a U-shaped relationship between BMI and risk of falls (Trevisan et al., 2019). Using a BMI of 23.5 as reference, the pooled RR of any fall ranged between 1.09 (CI 1.04, 1.15) for a BMI of 17.0, to 0.98 (CI 0.95, 1.01) for a BMI of 27.5, and 1.07 (CI 0.92, 1.24) for a BMI value of 37.5. The risk of a falls-related injury decreased with increasing BMI and ranged from 1.06 (CI 0.77, 1.46) for a BMI of 17.0 to 0.79 (CI 0.46, 1.37) for a BMI of 37.5.

Nutritional Status

Malnutrition is common in older adults, although less common in community settings compared to residential settings (Kaiser et al., 2010). In a mini review of nutritional status and falls Vance et al. report that in the general population studies reviewed, the prevalence of malnutrition was low (ranging from 3-12%), however overall malnutrition was associated with an increased risk of falls particularly in those 75+ years (Vance, Delbaere, Sturnieks, Haveland, & Lord, 2016). A more recent systematic review and meta-analysis found an increased falls risk for people who were malnourished versus those that were well nourished (RR 1.64, CI 1.18-2.28) but no increased risk of recurrent falls (Trevisan et al., 2019).

Joint and Bone Conditions

Older adults with joint conditions such as rheumatoid arthritis and osteoarthritis are susceptible to falls (Brenton-Rule, Dalbeth, Bassett, Menz, & Rome, 2015) (Smith, Higson, Pearson, & Mansfield, 2018). Pain and impaired mobility can affect balance and postural stability resulting in increased falls risk (Byun, Kim, & Kim, 2020). A large cross-sectional study (N=322,962) using data from the Korean Community Health Survey examined the association between arthritis history and falls in adults 40 to 70+ years (J. W. Lee, Kang, & Choi, 2021). Those

diagnosed with arthritis at any point during their lifetime were significantly more likely to fall (≥1 time or ≥2 times per year) compared to those never diagnosed (OR 1.42, CI 1.38–1.46 and OR 1.69, CI 1.62–1.76 respectively) when controlling for potential confounds. Similarly, those currently being treated for arthritis were significantly more likely to fall compared to those not currently receiving treatment (adjusted OR 1.35, CI 1.31–1.39 and adjusted OR 1.56, CI 1.50–1.63 respectively). These findings were consistent across all age bands.

van Schoor et al. examined whether a clinical diagnosis of knee or hip osteoarthritis (OA) was associated with an increased fall risk using baseline and follow-up data from 2,535 participants (aged 65-85 years) from the EPOSA study (a European study focusing on the determinants and burden of OA in older adults) (van Schoor et al., 2020). The association between clinical knee OA and recurrent falls was significant after adjustment for confounds (RR=1.55, CI 1.10-2.18). Clinical hip OA was unrelated to falls or recurrent falls in a fully adjusted model. Similar results were found in a recent systematic review and meta-analysis examining the association between hip and knee osteoarthritis (21 studies with over 145,000 participants) (Deng et al., 2021). Knee (RR 1.35, CI 1.20-1.51) but not hip osteoarthritis was associated with a higher prevalence of falls compared to non-OA participants.

Osteoporosis is a condition in which the bones become less dense and more likely to fracture. Associated changes to balance, posture and muscle strength may increase the risk of falls. In a study of postmenopausal women (with and without osteoporosis) the presence of osteoporosis increased the risk of falls (OR 2.17, CI 1.29, 3.65) after adjustment for potential confounds (Beserra Da Silva et al., 2010).

Falls History

One of the most predictive falls-related risk factors is a history of falls (Poss & Hirdes, 2016). Deandrea et al.'s 2010 meta-analysis estimated that a history of falls was associated with a 3-fold risk of falling (OR 2.92, CI 2.50-3.40) (Deandrea et al., 2010). Similar estimates have been found in more recent studies. Using data from a nationally representative sample of Medicare beneficiaries from the National Health and Aging Trends Study (NHATS), Helsel et al. found falls in the past year (OR 2.16, CI 1.61-2.89), and multiple falls in the past year (OR 2.94, CI 1.89-4.55) were significant predictors of 4-year falls in 3,170 community-dwelling older adults (Helsel, Kemper, Williams, Truong, & Van Puymbroeck, 2021). A community-based prospective cohort study of 1,000 older adults in Kerala, India (mean age 72.7 (SD=7.2) years found a history of falls in the previous year adjusted for potential confounds predicted a fall in the following year (OR 2.25, CI 1.60-3.15) (Sasidharan et al., 2020). A case-control study in an Accident Service Unit in Sri Lanka investigated risk factors for domestic falls for 200 older adults (60+ years). History of previous domestic falls after age 50 was an unadjusted significant risk factor (OR 2.36, CI 1.27-4.39) for falls in the home (Prathapan et al., 2017). Finally, in a cohort of 765 community-dwelling US older adults (70+ years) fall history predicted incident injurious falls (HR 1.82, CI 1.39–2.39), when adjusted for covariates (Ward et al., 2015).

Urinary Incontinence

Urinary symptoms such as frequency, urgency, nocturia, and urinary incontinence have been associated with an increased risk of falls in older adults (Soliman, Meyer, & Baum, 2016). A recent systematic review and meta-analysis of longitudinal studies of the impact of nocturia on risk of falls found a relative risk of 1.20 (CI 1.05-1.37) for falls with an absolute increase in annual risk of falling by 5.5% among people 65 years old and by 7.5% among those 80 years old (Pesonen et al., 2020). A further systematic review and meta-analysis of 38 articles examined the link between urinary incontinence and falls (Moon et al., 2021). The overall OR for falls was 1.62 (CI 1.45–1.83) and a subgroup analysis by age showed an OR of 1.59 (CI

1.31-1.93) for those aged 65 and over. Odds ratios were similar for urgency and stress incontinence.

Foot Problems

Foot problems are common in older adults and may contribute to falls (Pol, Forghany, Hosseini, Taheri, & Menz, 2021). A 2018 systematic review and meta-analysis identified six cross-sectional and nine prospective studies for review that had examined the associations between foot problems and falls in older adults (Menz, Auhl, & Spink, 2018). The reviewed articles found several foot conditions increased the risk of falls including plantar fasciitis. foot pain, hallux valgus, and lesser toe deformity. Meta-analysis of these latter three variables found each significantly associated with falls OR 1.95 (CI 1.38–2.76), OR 1.89 (CI 1.19–3.00) and OR 1.67 (CI 1.07–2.59) respectively.

Multiple Health Risk Factors

While many studies examine the role of individual health conditions as independent risk factors for falls, few investigate the role of multiple chronic conditions or patterns of multimorbidity. Older adults develop multiple chronic diseases as they age (Vetrano et al., 2020). Using data from a large population-based survey (Canadian Community Health Survey- Healthy Aging) Sibley et al. examined the associations between falls, individual chronic conditions and multi-morbidity in community-dwelling adults aged 65 years+ (Sibley, Voth, Munce, Straus, & Jaglal, 2014). Among older adults with no chronic conditions falls in the previous twelve months were significantly lower (11.4%) compared to those with any chronic condition (21.2%) and the risk of falls increased with the number of chronic conditions reported. The authors also explored patterns of chronic conditions (using clusters analysis) and their associations with falls. Relative to a "low chronic disease" cluster, two clusters dominated by hypertension (OR, 1.2) and chronic obstructive pulmonary disease (OR 1.6) respectively were associated with an increased risk of falls (CIs not reported). A more recent survey study of older adults (mean age 72.7 years (SD=6.5)) in Finland found those with five (OR 11.70, CI 2.99–46.44) and six or more (OR 8.60, CI 2.10–35.17) chronic diseases had increased risk of recurrent falls adjusted for age and gender (Immonen et al., 2020). These authors also found that clusters of chronic diseases were related to falls. A cluster dominated by osteoporosis, (OR 5.65, CI 1.23–25.85) and a cluster dominated by a high prevalence of multiple chronic conditions (OR 13.42, CI 2.47–72.96) were significantly associated with recurrent falling.

3.2.5 Psychological Characteristics

Sleep Quality

Poor sleep is associated with morbidity (e.g., obesity, diabetes, hypertension and cognitive decline) and mortality (Garbarino, Lanteri, Durando, Magnavita, & Sannita, 2016) and sleep complaints increase with age (Miner & Kryger, 2020). Poor sleep quality has been associated with an increased risk of falls (T. Ma et al., 2017) due to effects on balance and cognition, or the result of medications used to treat insomnia (see section on the effects of hypnotics and sedatives). Data from the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS) was used to examine the association between inadequate sleep and the experience of falls at 1-year follow-up in 1,071 community-dwelling people aged 65+ years (mean 71 years) (Takada et al., 2018). Multivariate analysis showed that participants reporting poorer subjective sleep quality had higher odds of experiencing falls during 1-year follow-up (OR 1.50, CI 1.20-1.89), adjusted for demographics and health characteristics. Participants with the poorest sleep quality had significantly increased odds of experiencing falls compared to those with better sleep quality (adjusted OR 2.14, CI 1.09-4.22). A recent study found the effect of

sleep quality on falls in 4,579 adults aged 60+ was partially mediated by depression (J.-H. Liu, Ma, Sun, Xu, & Pan, 2021).

Depression

Depression is common in later life and is an independent risk factor for falls (Grenier, Payette, Langlois, Vu, & Bherer, 2014). In a large nationally-representative study of US adults, Bergen et al. analysed data to examine risk factors associated with increased fall and fall injury risk for adults 65+ years (Bergen et al., 2019). Depression had the strongest association with falls (38.6%, CI 46.8-49.7) and fall injury (21.6%, CI 20.4-22.8) when adjusted for demographic, geographic, functional, and health characteristics. A systematic review and meta-analysis of prospective studies of depressive symptomatology as a risk factor for falls in older people (N=21,455) found that higher levels of depressive symptoms at baseline resulted in a greater likelihood of falling during follow-up (OR 1.46, CI 1.27-1.67) (Kvelde et al., 2015). An analysis of data from the New Zealand LiLACS study found both Māori (OR 2.003, CI 1.231-3.258) and non-Māori (OR 2.756, CI 1.672-4.544) with depression were more likely to fall than non-depressed Māori (reference group) when adjusted for age and sex (Atlas, Kerse, Rolleston, Teh, & Bacon, 2017). Depression also predicted hospitalisations from falls for Māori (OR 5.586, CI 2.453-12.718, adjusted for age and sex) and non-Māori (OR 4.212, CI 2.384-7.444, adjusted for sex).

Different types and patterns of falls have been linked to depressive symptoms. In a sample of 765 community-dwelling participants aged 70+ in the MOBILIZE Boston Study, Tchalla et al. found four clinically distinct trajectories of falls: cluster falls, increasing falls, chronic recurring falls, and no falls. Symptoms of depression (measured by the CES-D) were predictive of membership of all four groups (Tchalla et al., 2014).

An earlier study using data from MOBILIZE found clinically significant depression was independently associated with an increased risk of both indoor and outdoor falls (L. Quach et al., 2013) . An examination of data from the Irish Longitudinal Study on Ageing (50+ years) found that depression was associated with an increased risk of total falls (OR 1.58. CI 1.31-1.89), accidental falls (OR 1.24, CI 1.00-1.52) and unexplained falls (OR 1.89, CI 1.45-2.46) after controlling for numerous covariates (Briggs, Kennelly, & Kenny, 2018).

The association between depression and falls may also be bidirectional, with falls leading to avoidance behaviours, social isolation, lower self-efficacy and subsequent depression (Iaboni & Flint, 2013). Somatic symptoms of depression such as weight loss and cognitive deficits may also lead to falls (Byun, Kim, & Kim, 2021).

Loneliness

Increasing numbers of older adults are living alone as they age (Klinenberg, 2016). Loneliness is commonly defined as the discrepancy between a person's preferred and actual level of social contact (Newall & Menec, 2019). Loneliness is a subjective experience of lacking sufficient closeness to a significant or intimate other or to close friends and family. Social isolation can be defined as an “objective state of having minimal social contact with other individuals” (Newall & Menec, 2019). A recent systematic review of the literature notes the limited research on the links between loneliness, social isolation, and falls risk in older adults (Petersen et al., 2020), however all 17 studies reviewed found falls in older people associated with not only loneliness and social isolation, but also living alone. An analysis of longitudinal data from the National Health and Aging Trends Study in the US was undertaken to examine whether social isolation predicts falls in older adults (N=7609, mean age 78.4 years (SD=8.19)) (Pohl,

Cochrane, Schepp, & Woods, 2018). Social isolation was predictive of falls at 1-year follow-up (OR 1.08, CI 1.02-1.14) controlling for age, gender and education. Two studies that analysed cross-sectional data from the Korean Community Health survey found living alone was associated with a higher risk of falls (OR 1.13, CI 1.05-1.21) (Choi et al., 2014), and fall injuries (OR 1.134, CI 1.065 1.207) (Noh et al., 2017) adjusted for covariates.

Gender differences in living arrangements and social networks in older adults may contribute to differential risk for falls. Analysis of data from 3,112 participants (aged 60+, mean age 71.5 years (SD=9.9)) in the Swedish National Study on Aging and Care in Kungsholmen found living alone was a risk factor for falls for women at 4-year follow-up (HR 1.83, CI 1.13-2.96) controlling for age and education, but not for men (Ek et al., 2019).

Social engagement may also interact with other risk factors for falls. A cross-sectional analysis using baseline data from an observational prospective cohort study (Boston RISE) among 430 community-dwelling older adults (65+, mean 76.56 years (SD=7.0)) found mild cognitive impairment (MCI) significantly associated with number of self-reported falls after adjusting for demographics and comorbidities (RR=1.90, CI 1.34-2.70) (L. T. Quach et al., 2019) . This finding was moderated by social engagement in that those with low social engagement and MCI had a 97% higher risk of falls, while for those with high social engagement MCI was not related to falls.

Falls Risk Awareness

Falls risk awareness is usually the result of previous falls and may result in adaptations to reduce the risk of falls. For instance, older adults with an increased falls risk awareness may adapt their behaviours e.g., altering their gait and speed in potentially hazardous environments (Mihaljcic, Haines, Ponsford, & Stolwyk, 2017). A cross-sectional study of falls risk factors with 1,826 community-dwelling older adults aged 60+ years found that those with lower falls risk awareness were at greater risk of falls across all older aged groups: 60.0-69.9 years (OR 1.05, CI 1.01-1.09), 70.0-79.9 years (OR 1.09, CI 1.04-1.13), 80+ years (OR 1.13 CI 1.04-1.22) (Moreira, Rodacki, Pereira, & Bento, 2018).

Fear of Falling

Fear of falling (FoF) can be defined as a loss of confidence in, or anxiety about, walking or moving. It is common to experience anxiety after a fall but FoF also occurs in older adults with no physiological risk factors for falls (Turunen et al., 2020). Older adults may limit their daily activities due to FoF and further exacerbate existing physical weakness, thus increasing the future risk of falls (R. Yang & Pepper, 2020). Deandrea et al.'s 2010 systematic review and meta-analysis of risk factors for falls in community-dwelling older adults found fear of falling to have one of the strongest associations with recurrent falls (OR 2.51, CI 1.78-3.54) (Deandrea et al., 2010). A similar risk was found in a prospective cohort study which investigated the prevalence and distribution of 8 modifiable risk factors in 1,077 patients (aged 65+, mean age 78.5 years (SD=7.8)) presenting after a fall at an A&E department in Amsterdam (van Nieuwenhuizen et al., 2010). Fear of falling was independently associated with recurrent falls in multivariate logistic regression (OR 2.2, CI 1.3-3.7). A more recent study using a nationally representative sample of Medicare beneficiaries from the National Health and Aging Trends Study (NHATS) found that fear of falling (OR 1.77, CI 1.45-2.16) was a significant predictor of 4-year falls in 3,170 community-dwelling older adults.

Falls self-efficacy (FSE) is a related term for FoF used in the literature. A secondary analysis of data from a longitudinal study of 47 community-dwelling older adults (aged 70-93 years, mean age 78.9 (SD=5.5)) examined the association between falls FSE and fall events (R. Yang

& Pepper, 2020). FSE was associated with reduced risk of falls after adjusting for age, gender and fall history (IRR 0.96, CI 0.92–0.99). High FSE participants were less likely to fall than those with low FSE.

A sub-study of the Steps to Avoid Falls in Elder (SAFE) trial examined the associations of falls efficacy, postural balance, and their interaction with fall risk in community-dwelling older adults (65+ years) who presented and were discharged from the emergency department for a fall or falls-related injury (Yong-Hao et al., 2017). There was no significant association between falls efficacy and fall risk when adjusting for covariates however, falls efficacy interacted with postural balance such that those with high falls efficacy but poor postural balance were at greater risk of fall compared to those with low falls efficacy. The authors suggest this may indicate risk taking behaviour or inaccurate fall-risk appraisal in over-confident adults with high falls efficacy.

Fear of falling and FSE may also impact falls risk indirectly (Yong-Hao et al., 2017). A cross-sectional study using baseline data gathered for a randomized controlled trial (the PASSWORD study) investigated the relationship between concern about falling and falls and the role of neuroticism in 314 community-dwelling older adults (70- to 85 years) (Turunen et al., 2020). Path analysis showed that a significant relationship between concern about falling and indoor and recurrent outdoor falls was mediated by neuroticism. Data from an observational cohort study of Italians was used to investigate whether the capacity for judgment was associated with fear of falling, activity restriction and the risk of falls in 2,625 older adults (mean age 75.4 years (SD=7.3)) (Trevisan et al., 2020). The authors found that fear of falling was related to recurrent falls when adjusted for potential confounds. In addition, the poorer the judgement capacity the stronger the relationship between fear of falling and the risk of experiencing falls.

3.3 Summary of Evidence: Environmental/Extrinsic Risk Factors

3.3.1 Medications

The use of certain medications has been recognized as a risk factor for falls in older adults and may be a modifiable risk factor in falls prevention (Park, Satoh, Miki, Urushihara, & Sawada, 2015). For instance, a narrative review of articles published up to 2012 identified six key medication types as risk factors (FRIDs – fall-risk inducing drugs) for falls in older adults: psychotropic medications, antiepileptics, cardiovascular medication, diabetes drugs, nonsteroidal anti-inflammatory drugs, and vitamin D (Ambrose et al., 2013). Many of these medications are not only associated with falls independently but are also markers for underlying disease processes associated with falls.

Psychotropic Medications

The relationship between psychotropic drugs and falls has been previously established (Leipzig, Cumming, & Tinetti, 1999; Woolcott et al., 2009). A systematic review by Ming and Zecevi of 18 articles investigated the association of medications on recurrent falls (defined as two or more falls in a 12-month period) in community-dwelling older adults (Ming & Zecevic, 2018). A clear finding from the studies reviewed was that the use of anti-depressants, sedatives or hypnotics, and anti-epileptics were all related to recurrent falls in older adults even when adjusting for confounds.

Antidepressants

As noted earlier depression is an independent risk factor for falls (Grenier et al., 2014) and there is evidence to suggest that antidepressant use is also a risk factor for falls irrespective of depression severity (Iaboni & Flint, 2013). Using the 2009–2013 Medicare Current Beneficiary

Survey (MCBS) Cost and Use files from the Centers for Medicare and Medicaid Services (CMS) Haddad et al. examined anti-depressant subclass use and fall risk (self-reported falls) in 8,742 community-dwelling older Americans aged 65+ (Haddad, Luo, Bergen, Legha, & Atherly, 2021). All antidepressant medications in the study were associated with increased risk of falls. However, after adjusting for potential confounders only selective serotonin reuptake inhibitor (SSRI) use and serotonin norepinephrine receptor inhibitor (SNRI) use remained significantly associated with increased risk of falling. Risk of falling increased by around 30% among those who used a SSRI (RR 1.32, CI 1.07-1.62) or a SNRI (RR 1.29, CI 1.13-1.47), compared to non-users. Antidepressant use may also mediate the relationship between depression and falls. In a study of 3,565 participants from the Health and Retirement study, Lohman et al. found that while individuals with major depressive disorder were approximately twice as likely to report a fall (OR 1.92, CI, 1.412-2.621) and 86.4% more likely to report a falls-related injury (OR 1.864, CI 1.221-2.847), use of antidepressant medication mediated these associations accounting for approximately 19.1% and 17.8% of the total effects respectively (Lohman, Fairchild, & Merchant, 2020).

Sedative-Hypnotic Drugs

Benzodiazepines (BZDs) and hypnotic non-benzodiazepines (Z-drugs) (e.g., zaleplon, zolpidem, zopiclone and eszopiclone) are commonly prescribed for older adults for insomnia, especially among women (Shaw et al., 2019). Ming and Zecevic's systematic review found strong evidence for the impact of BZDs on recurrent falls in older adults with four studies showing adjusted odds ratios ranging from 1.56 (CI 1.00-2.43) to 3.71 (CI 1.48-9.26) across long, intermediate and short-acting drugs (Ming & Zecevic, 2018). A prospective Dutch study on the prevention of osteoporotic fractures recorded medication use from pharmacy dispensing records and falls incidents during the study period (Ham et al., 2014). Use of benzodiazepines was related to an increased risk of falls (HR 1.32, CI 1.02-1.71) when controlling for confounds.

The relationship between Z-drugs and falls risk in older adults in less clear. A systematic review and meta-analysis evaluating the association between Z-drugs and fractures, falls and injuries found a significant increased risk for fractures (OR 1.63, CI 1.42–1.87) and risk of injuries (OR 2.05, CI 1.95–2.15) but not for falls (OR 2.40, CI 0.92–6.27) (Treves, Perlman, Kolenberg Geron, Asaly, & Matok, 2018). However, a large prospective study of community-dwelling older men (65+) found non-benzodiazepine hypnotic use was associated with an increased risk of any falls (RR 1.44, CI 1.15-1.81) and recurrent falls (≥2) (RR 1.51, CI 1.07-2.14) (Diem et al., 2014).

Antiepileptics

Two recent systematic reviews investigated the use of antiepileptic drugs (AEDs) and their association with falls and/or recurrent falls in older adults. The first found significant adjusted estimates for any fall ranging from 1.51 (OR) to 2.8 (OR) and for recurrent falls 2.56 (RR) to 2.6 (OR) in older adults 60+ (Haasum & Johnell, 2017). The second review also found significant relationships between AED use and falls and recurrent falls with odds ratios of 1.75 to 6.2 for 1 fall or at least 1 fall and from 2.56 to 7.1 for frequent falls (Maximos, Chang, & Patel, 2017). The authors caution that some of the ORs are accompanied by large confidence intervals suggesting estimates may not be precise. Relative risks ranged from 1.29 to 1.62.

Narcotics and Analgesics

Opioid analgesics, such as codeine and oxycodone, are commonly prescribed for chronic pain and use is more prevalent among older adults (60+) than younger adults (Yoshikawa et al.,

2020). A recent systematic review and meta-analysis found an increased risk of falls (ES 0.15, CI 0.02-0.27), fractures (ES 0.71, CI 0.45-0.97), and fall injuries (ES 0.40, CI 0.24-0.56) among older adults who used opioids.

Evidence for the influence of other analgesics on falls is reported in a study of 57,383 patients (mean age 67.0 years (SD=12.8)) with knee osteoarthritis (KOA) (Taqi, Gran, & Knaggs, 2021). Within the first six months of KOA diagnosis, the reported HR for NSAIDs was 1.72 (CI 1.43-2.07), and for paracetamol 1.98 (CI 1.68- 2.33) adjusted for potential confounds, while between 6 and 12 months after KOA diagnosis, the adjusted HRs were 1.47 (CI 1.21-1.78), and 1.92 (CI 1.63-2.26) respectively. In a review article of 16 studies evaluating NSAID use by older adults and fall risk, the majority found that patients using NSAIDs had a higher incidence of falls compared with those not taking NSAIDS (Findley & Bulloch, 2015).

Cardiovascular Medications

Cardiovascular drugs are commonly prescribed for older adults. A 2018 systematic review of 131 articles and 16 drug classes was undertaken on the association between cardiovascular medications and falling, recurrent falling and injurious falling in older adults (de Vries et al., 2018). Meta-analysis of unadjusted ORs showed that digitalis and digoxin may increase the risk of falls and statins may reduce the risk. In addition, meta-analysis of adjusted ORs found significant results for loop diuretics which increased the risk of falls and beta-blocking agents which reduced the risk of falls. For other cardiovascular medications groups, outcomes were inconsistent (e.g., antiarrhythmics, anti-hypertensives). A recent 3-year community-based prospective cohort study of older adults 65+ based in Kerala, India found an inverse relationship between the use of antihypertensive medications and falls (OR 1.53, CI 1.10-2.13) and the authors suggest this may a result of a high proportion of uncontrolled hypertensives in their study population (Sasidharan et al., 2020).

A key finding from de Vries et al. is that focusing on broad pharmacological groups may mask the effect of specific pharmacological subgroups on falls and that falls risk may vary among these different subclasses of medications. This is highlighted by the inconsistent findings in the systematic review by Ming and Zecevic in studies looking at the impact of diuretics on recurrent falls (Ming & Zecevic, 2018).

Other Medications

Several other medications not reviewed above have been studied in relation to their role in falls among older adults. Ming and Zecevic in their review note that laxatives have been associated with the likelihood of recurrent falls (OR 2.14, CI 1.02-4.49) (Ming & Zecevic, 2018). Askari et al. found evidence for the use of anti-Parkinson drugs (OR 1.59, CI 1.02–2.46), nasal preparations (OR 1.49, CI 1.07–2.08), and ophthalmologicals (OR 1.51, CI 1.10–2.09) were related to recurrent falls when adjusted for confounds (Askari et al., 2013). As noted earlier, insulin-treatment for diabetes has been found to be associated with a greater risk of falls (Y. Yang et al., 2016; Yau et al., 2013) .

Polypharmacy

Not only do specific medications increase the risk of falls, but the number and combination of medications may also be important. Ming and Zecevic in their systematic review found that polypharmacy was associated with recurrent falls in a number of studies and suggested that it could increase the possibility of falling by up to 2 times (Ming & Zecevic, 2018). A large population-based study of community-dwelling 65+ older adults in Sweden found the number of medications used was associated with increased risk of falls, with the use of ten or more drugs related to nearly twice the risk of hospitalization from fall injury after adjusting for

confounds including FRIDs (adjusted OR 1.76, CI 1.66 to 1.88) (Laflamme, Monarrez-Espino, Johnell, Elling, & Moller, 2015). Risk increased slightly with each additional medication among those individuals using at least one FRID. However, an increased risk for falls for those not using FRIDs remained even for those on fewer than ten medications in total.

There is a suggestion that polypharmacy may only be significant when particular FRIDs are included (Richardson, Bennett, & Kenny, 2015). Richardson et al. used the Irish Longitudinal study on Ageing (TILDA), a large prospective cohort study, to examine the interaction between polypharmacy and medications associated with falling. They found no association between polypharmacy and falls after adjusting for covariates (e.g., demographics and co-morbidities), however polypharmacy with the addition of antidepressants increased the risk of any fall, the number of falls and the rate of injurious falls. The addition of benzodiazepines to polypharmacy also increased the risk of injurious falls (use of benzodiazepines was also related to number of falls without polypharmacy).

A New Zealand study investigated the role of increased anticholinergic and sedative load (as defined by the Drug Burden Index, DBI) on the risk of falls in 71,825 community-dwelling older people (65+) (Jamieson et al., 2018). Increasing DBI levels were associated with increased odds of falls: 0< DBI ≤1 (OR 1.11, CI 1.07-1.15), 1< DBI ≤3 (OR 1.27, CI 1.22-1.32), >3 DBI (OR 1.41, CI 1.32-1.50) after adjustment for 18 possible confounding factors including walking speed, activities of daily living (ADL) function, and comorbidities.

Medication Adherence

There is evidence that withdrawal from or non-adherence of some medications may increase the risk of falls in older adults. Using date from the Maintenance of Balance, Independent Living, Intellect, and Zest in the Elderly of Boston (MOBILIZE Boston) Study, Berry et al. investigated whether poor medication adherence increased the risk of falls in a community-based cohort of seniors (N=654, mean age 78 years) (Berry et al., 2010). The increased rate of falls in the group with low medication adherence compared with the group with high medication adherence was 50% (RR 1.5, CI 1.2–1.9) after adjusting for other variables, including age, sex, cognitive function, and total number of medications. Dillon et al. undertook a prospective cohort study, recruiting participants from community pharmacies in the Republic of Ireland and measuring 5-day gaps in prescription-refills (indicative of poor adherence) (P. Dillon, Smith, Gallagher, & Cousins, 2019). Measurement of falls at 12-month follow-up showed 18% increased risk of a self-reported injurious fall for each 5-day gap in antihypertensive medication refill adherence after adjusting for risk factors including age, gender, fall risk increasing medication and comorbidities.

3.3.2 Home Hazards and Environment

Hazards in the home, neighbourhood and environment offer potential avenues for intervention to reduce falls risk. Modifiable risk factors in the home include lighting, stair and bath rails, clutter, and wet surfaces. Neighbourhood and environmental factors amenable to intervention include uneven footpaths and steps, litter, and traffic issues. The social and built environment within communities also plays a role through perceptions of safety and trust.

In the Home

A recent scoping review of published academic articles (from 1996 to 2019) identified 14 studies (N=5,977, mean age 78 years) on in-home environmental hazards (Keglovits et al., 2020). Seventeen in-home environmental hazards were reported on: throw rugs/carpets, clutter, cords/wires, poorly placed light switches, items placed too low, items placed too high, no grab

bars, toilet seats too low, uneven floor surfaces, slippery/wet surfaces, snowy/icy surfaces, backless/unsupportive shoes, unsteady stairs, inadequate lighting, inadequate heating/cooling, step stools without railings, and pets. A similar review in 1997 found baths a frequent home hazard for falls (Clemson, 1997) but this was not identified by any of the articles reviewed as a falls hazard in the more recent scoping review. The authors suggest this may reflect a change in housing design and a preference for showers (Keglovits et al., 2020). The most common areas for in home falls identified in the review were the bedroom, kitchen, driveway, and basement. In the retrospective study of InterRAI assessment records of community-dwelling older adults in Hong Kong mentioned earlier (Qian et al., 2021) the authors found that environmental hazards related to floor and carpeting (OR 1.41, CI 1.02-1.93), access to the home (OR 1.38, CI 1.10-1.72) and room accessibility within the house (OR1.10, CI 1.01-1.2) were associated with increased fall risks when controlling for other risk model factors.

Outside the Home

The risk factors associated with outdoor falls differ from those of indoor falls. While indoor fallers are more likely to be frail with poor health characteristics, outdoor fallers are more likely to be healthy and active (Kelsey et al., 2012). Access to the outdoor environment contributes to healthy and active ageing. However, environmental features may also contribute to falls in older adults. Environmental hazards that may influence falls risk include uneven streets and footpaths, curbs, stairs, drains, gratings, potholes, vehicle and pedestrian traffic, footpath clutter (bins, hoardings) and wet or slippery surfaces (Chippendale & Bear-Lehman, 2011). Data from the National Health and Aging Trends Study (NHATS) was used to identify neighbourhood risk factors linked to the odds of experiencing recent falls at the one-year follow-up in older adults 65+ (N=4,802) (S. Lee, Lee, & Ory, 2019). Significant predictors of falls at follow-up were exposure to increased obstructions on footpaths or streets near participants homes (litter/broken glass, or trash) (OR 1.81, CI 1.25–2.62) and to increased problems in walking surfaces (uneven walking surfaces or broken steps) (OR 1.68, CI 1.25–2.27). Consistent exposure (at both baseline and follow-up) to litter or trash on the streets near their homes (OR 1.88, CI 1.25–2.84) was also associated with an increased likelihood of reporting recent falls at follow-up. Adjustments were made for age, sex, race, marital status, and job status.

Socially cohesive neighbourhoods in which older adults report high levels of belonging and trust may also contribute to falls risk. Data from the Health and Retirement study in the US was used to examine the relationships between perceptions of the neighbourhood environment and falls among community-dwelling older adults 65+ (N=9,259) (Nicklett, Lohman, & Smith, 2017). Neighbourhood cohesion was related to reduced risk of falls. In models adjusting for sociodemographic and health characteristics each unit increase in average neighbourhood social cohesion was associated with 4% lower odds of experiencing a fall (OR 0.96, CI 0.93–0.99) and 6% lower odds of experiencing multiple falls (OR 0.94, CI 0.90–0.98). Recent New Zealand data also shows that falls are related to neighbourhood conditions (Stephens & Birchall, 2021). Data from the 2020 survey wave of the New Zealand Health, Work and Retirement (HWR) longitudinal prospective cohort study showed that perceptions of housing quality were related to falls. Falls were less likely among the 75+ age group, if participants reported better housing condition, higher perceptions of housing satisfaction, and neighbourhood satisfaction, trust, and accessibility.

As mentioned earlier, weather can be a contributing factor to falls risk particularly in extreme environments (Elvik & Bjørnskau, 2019). Qian et al.'s large study of InterRAI records of

community-dwelling older adults in Hong Kong (Qian et al., 2021) found the number of very hot and humid days was related to lower risk of falls but the number of cold days or number of days with heavy rains was associated with a small increase in risk.

Assistive Devices

The use of walking aids may indicate mobility issues and subsequent fall risk. Taylor et al., found that using walking aids indoors (IRR 1.616, CI 1.079-2.419) and outdoors (IRR 1.667, CI 1.141-2.437) was related to falls, and in a systematic review and meta-analysis of risk factors for falls in community-dwelling older people the use of a walking aid was related to falls (OR 2.46, CI 1.91-3.15) and recurrent falls (OR 3.05, CI 1.87-4.95)(Deandrea et al., 2010).

Footwear

An early review of the literature on risk factors for falls among older adults identified footwear as a potential contributor to the incidence of falls (Ambrose et al., 2013). For instance, the authors note that the wearing of heels greater than 2.5cm high was found to be associated with a nearly 2-fold increase in risk of falls compared to wearing canvas shoes. However, a more recent systematic review found only limited evidence for type of footwear as a risk factors for falls (Davis, Haines, & Williams, 2019) and the authors note a lack of methodological rigour in most studies reviewed.

4 Preventative interventions among older adults/kaumātua

The purpose of the following section is to review the recent literature published after 2010 on interventions targeting modifiable risk factors to prevent falls in older adults/kaumatua.

A total of 4,643 papers were identified during the search and, based on the abstract or title, 271 papers that addressed interventions targeting modifiable risk factors were retrieved. Of these papers, 69 measured falls and are included in this review (see Appendix). Studies were included if they were published since 1st January 2010, the sample age range began from at least 55 years, and they measured falls. Some studies that did not measure fall risk were included if there were no studies on the specific topic that measured fall risk. In the case of literature reviews, the most recent review on each topic was included.

Studies were excluded if they focused specifically on a population with underlying medical conditions or disabilities, they did not measure fall rate (except in the case where there were no studies on the topic including fall rate), or the sample age range included people below age 55 years. If an individual study was covered by an included literature review, it was excluded from this review.

4.1 Key Findings

Falls are multifactorial events, and thus require a multifactorial approach. While there is evidence for some single interventions reducing falls in older adults, the most effective interventions are ones which target multiple modifiable risk factors at once, preferably individually determined for each participant following a falls risk assessment. Multi-component interventions that involved addressing multiple factors at once but without being tailored to each participant were also effective but being able to target specific risk factors based on the participant's needs tends to produce consistently positive results in reducing falls. A key factor in the efficacy of a multifactorial intervention is whether it contains active interventions carried out with the participant which tend to be most effective, or if the assessment only results in referrals to other services for suggested interventions, which tends to lack efficacy.

Home modifications appear to be instrumental in reducing fall risk, and there is evidence for a home modification intervention being effective both as a stand-alone intervention, and as part of a multifactorial intervention. There is some evidence that multifactorial interventions without home modifications are not as effective as interventions that contain a home modification component. Most important seems to be the involvement of occupational therapists in the assessment of homes and recommendation of subsequent modifications. Home modification interventions without the involvement of occupational therapists tend to be less effective. The key factor in assessing a home for fall prevention is to understand how the resident interacts with the environment and the specific behaviours surrounding the risks, further demonstrating the importance of occupational therapists in the intervention.

Exercise is well-documented as an effective intervention for preventing and reducing falls in older people. Specifically, there is considerable evidence for strength and balance training in reducing falls, and power training has been shown to improve functional performance. The Otago Exercise Programme, incorporating strength, balance and walking, has been shown to effectively reduce falls. Tai chi is well-suited for older adults and promotes balance, strength and flexibility, all of which are risk factors for falls. Tai chi can be adjusted for the participant's individual capabilities and the difficulty can be reduced as necessary to make it accessible. The difficulty with exercise interventions is getting participants to adhere to the program, and often

there are a multitude of reasons why a person may not continue. Exercise programs are also not appropriate for some populations. Exercise is often prescribed as part of multifactorial interventions, and there is some evidence that multifactorial interventions containing an exercise component tend to be more effective than those without exercise.

Technology may be an important addition to fall interventions, as the addition of virtual reality to treadmill training improved the efficacy of the treadmill training, significantly reducing fall rate six months later. Training that incorporates exercises using the Wii Fit improves balance and walking speed and reduces fear of falling, however the current literature suggests there is no effect on fall rate.

There is a strong link between cardiovascular disorders and falls in older people, and there is evidence that addressing the underlying cardiovascular issue is effective as an intervention to reduce falls.

Many medications are known to increase falls risk but reducing the use of these medications is not as easy as simply removing them. Medication review and cessation of fall-risk increasing medications has been shown to effectively reduce fall rate, however participants often begin taking the medications again at the end of the studies. Underlying health conditions are the driver for use of fall risk-increasing medication, so these ongoing health concerns make long-term medication changes difficult to sustain.

Some interventions lack evidence for reducing falls as singular interventions but have been shown to improve other markers of fall risk. These interventions include Vitamin D supplementation (although the dosage is uncertain), dancing, aquatic exercise, yoga, footwear, education and vibration training. These interventions show potential but require further research in which the fall rate before and after the intervention is directly measured alongside the risk factors.

A challenge faced by all interventions is adherence to the programme. Exercise and medication reviews in particular are affected by high dropout rates, and home modifications are difficult to implement due to resistance from the residents to change their homes. It is important to work with participants to help them understand the purpose and benefits of the intervention, and to continue to follow up with them in order to help keep them engaged.

There is little evidence about interventions to reduce fall risk in older New Zealanders, and there is very little research on the effect of interventions in Māori or Pasifika. Further research is needed to reduce falls among New Zealand's kaumātua and other older adult populations.

4.2 Summary of Evidence: Modifiable risk factors targeted by interventions

4.2.1 Home assessment and modifications

The home is a dynamic environment deeply personalised to a person's way of life, but as discussed earlier, contains many different elements that have been found to be risk factors for falls. These elements can be modified either by professionals or by the resident themselves in order to minimise risk and create a safer home environment. A large population-based study (N=9,447, aged 70+ years) reported that the presence of home modifications at baseline predicted less functional decline at the two-year follow up (S. Y. Liu & Lapane, 2009). Home modifications are particularly useful in older homes, where accessibility and safety may not have been incorporated into the design. The modifications are implemented with the intention of creating safer, more comfortable and functional spaces for older people to carry out their daily tasks. The modifications may be small, such as removing a problematic rug or shifting

furniture to allow for more walking space, or could be major renovations, such as removing steps (J. Pynoos et al., 2010).

Checklists are among the cheapest and most accessible forms of home assessment and can be carried out by anyone, including the resident themselves, regardless of prior knowledge or training. Their accuracy, however, depends on the person completing the checklist, and whether they can objectively recognise important risks in the home. Checklists also tend to be generic and therefore miss the unique aspects of a person's environment (J. Pynoos et al., 2010).

Functional home assessments are more comprehensive and time-consuming, and therefore more expensive. They are, however, better suited for addressing how a person interacts with their environment and better at identifying individual elements of the environment that would be missed by generic checklists. It is important that home assessments take into account the way the resident interacts with their home environment and common activities which differ from person to person. For this reason, often a home assessment will include a demonstration from the resident of their common interactions with the environment (J. Pynoos et al., 2010). If a home risk is simply removed without consideration for how the resident interacts with the environment, fall risk may actually increase due to interfering with behavioural patterns, such as using a certain piece of furniture for support or a visual landmark, built up over long periods of time (J. Pynoos et al., 2010).

A recent review on environmental modifications reported three studies with a reduction in fall rates after environment modifications (Shafizadeh et al., 2020). One of these studies was New Zealand-based (Campbell et al. 2005) and reported fewer falls in a group of participants aged 75+ with severe visual impairment who received environment assessment and modification via occupational therapy in the 12 months following intervention. The studies reviewed generally took one of two approaches: environmental assessment and modification, which was carried out by occupational therapists and involved seeing the environmental elements as potential hazards that increase fall risk, or ecological dynamic approach, which focuses more on the resident's perception and judgement in mitigating fall risk. The ecological dynamic approach may be applicable not just inside the home, but also areas outside the home where they may maintain independence and function.

A systematic review from 2017 searched databases for articles published between 1990 and 2008 focusing on home modification strategies for fall prevention. There were 33 articles included in the review, 31 of which were randomized controlled trials. Home modifications were more effective for participants who had reported at least one fall in the year prior to intervention (Chase, Mann, Wasek, & Arbesman, 2012). Home modifications tend to be more effective in reducing falls among people who have reported multiple previous falls (J. Pynoos et al., 2010).

It is important to recognise that, along with an individual's health, functioning is also dynamic, and thus the environmental assessment process should be ongoing, allowing the home to adapt as the person's functionality changes (J. Pynoos et al., 2010)

Occupational therapist-led

Occupational therapists (OT) are well-suited to carrying out environmental assessments and modifications due to their extensive knowledge of the environments in which older people live and their activities of daily life. This type of intervention does tend to be more likely to lead to a significant reduction in falls when carried out by such a professional (J. Pynoos et al., 2010). A Cochrane review concluded that home improvements are effective, particularly when carried

out by an occupational therapist, and even more so when the resident is at high risk of falls (Lesley D Gillespie et al., 2012) .

An RCT compared OT-led home modifications with that of trained non-professional assessors, and a usual-care control group (Alison C Pighills, David J Torgerson, Trevor A Sheldon, Avril E Drummond, & J Martin Bland, 2011). While the primary outcome of this study was fear of falling, falls were recorded as a secondary outcome. There was no difference in fear of falling between groups, however the falls rate in the OT group was approximately half that of the usual care group, whereas the group who received the intervention from trained assessors did not show a reduction in fall rate. Additionally, adherence to recommendations was significantly higher in the OT-led modification group.

A systematic review found that home modifications improved function and reduced risk of falls in people with health conditions (Stark, Keglovits, Arbesman, & Lieberman, 2017a) . The strongest evidence for improved function was when the home modifications were implemented by occupational therapists as part of a multicomponent intervention. In this review, an intervention was considered multicomponent if it incorporated at least one other intervention alongside home modifications. Even when home modifications were implemented alone as a single-component intervention, there was strong evidence for effectively reducing fall risk if they were carried out by an occupational therapist.

There is some evidence that this type of intervention may be most useful in individuals at high risk of falling, but less so in low-risk individuals (Pighills, Ballinger, Pickering, & Chari, 2016) . One RCT found mixed results when comparing falls at follow up between a group of people who received occupational therapist-led home visits and modifications with a control group receiving usual care. There was no overall difference in fall incidence between the two groups, except between people with a history of falling prior to recruitment, where the intervention significantly reduced fall rate (Cumming et al., 1999, cited in Chase et al., 2012).

Non-occupational therapist-led

It appears that occupational therapists are crucial in implementing an effective home modifications intervention. The evidence from studies that implement home assessments and modifications without occupational therapists have mixed results but are largely unsuccessful.

A Tokyo-based study placed responsibility for modifications on the participants; the intervention group received education and practice regarding environmental safety, a residential safety checklist home hazard awareness program and education about how to modify their environment to reduce fall risk. There was no significant difference in falls at 52 weeks after intervention. At 12 weeks post-intervention, participants over the age of 75 years experienced significantly fewer falls than the control group, but this difference was not significant at 52 weeks (Tomoko et al., 2015).

A study reported in Stark et al. (2017a) compared home hazard removal by public health workers with exercise and control groups and found home modification delivered in this format did not have a significant effect on fall risk (Lin et al., 2007, cited in Stark et al., 2017a).

The Home Safety Self-Assessment Tool (HSSAT) was developed as a client-centred tool which is designed to be accessible to community-living older adults who are not receiving occupational therapy. The tool allows for assessments of hazards in the home and encourages older adults to take part in their own safety assessments and modifications. A case study implementing the use of the HSSAT describes the experience of a 78-year-old woman who had received occupational therapy, but was still unaware of her own home risks and how to address

them. The woman initially completed the HSSAT on her own but was not able to identify all hazards alone and required the help of a student for recognition and explanation of risks. Recommendations were then made for safety improvements, which the woman agreed to and allowed to be carried out. She indicated feeling positive about the changes and feeling safer in her home (Horowitz, Nochajski, & Schweitzer, 2013).

Older people's attitudes towards home modifications

People are reluctant to make changes to their homes, even after learning about the risks. They do not view the home as unsafe and value the current situation more than the suggested modifications (Kruse et al., 2010) or do not believe that the home modifications will have an impact on their risk of falling (J. Pynoos et al., 2010). The home is part of a person's self-image and older people value their independence in choosing how to decorate, rather than being mandated by safety recommendations (Kruse et al., 2010). One study reviewed in Karinkanta, Piirtola, Sievanen, Uusi-Rasi, and Kannus (2010) reported that the older adults most willing to accept modifications to their home as a fall prevention intervention are those who are most at risk of losing their independence already.

Focus group interviews revealed that older adults with visual impairment generally feel positive about home modifications, and may prefer them to other interventions due to being an easy, quick solution (L. Dillon, Duffy, Tiedemann, & Keay, 2018). Interviews were conducted with 19 community-dwelling older adults with visual impairment in 2011, and an emerging theme was that these participants did not blame the falls they had experienced on their visual impairment, but rather attributed them to bad luck, or not paying enough attention to their surroundings. A Cochrane review found little evidence of environmental modifications reducing fall risk in people with visual impairment. Six months after intervention, there was little difference in risk of falling, however the authors noted that the methodological limitations in the reviewed studies meant further research was needed (Jian-Yu et al., 2020).

4.2.2 Behavioural modifications

It is crucial to understand a person's daily activities and how they interact with their environment to achieve them to fully assess the risk posed by environmental hazards. Behavioural modifications are a potential intervention to address activities that may increase fall risk, and are often implemented alongside environment modifications (Jian-Yu et al., 2020).

A 2011 study in community-dwelling older women who had sustained a falls-related hip fracture assessed homes for fall risks and suggested targeted modifications of the home environment and behaviours in activities of daily life (ADLs) to prevent falls. Of the 95 participants, 19 reported at least one fall during the follow up period. Participants with two or more risk factors that were left uncorrected had a significantly higher risk of falling that those with less than two uncorrected risk factors (OR 4.58, CI 1.472-4.250). An increase in adherence to the recommendations predicted a lower fall rate (OR 0.749, CI 0.594-0.945 for a 10% increase in adherence) (M Di Monaco et al., 2011).

A recent clinical RCT provided guidelines for modification of environmental and behavioural risk factors for falls in participants with hypertension aged between 65 and 75 years (Guerra et al., 2021). The intervention was effective in reducing the occurrence of falls in the intervention group. While falls were reported in both groups, only 6.9% of participants in the intervention group fell compared with 20% of participants in the control group. There was a 34.48% relative risk reduction for falls in the intervention group (Guerra et al., 2021).

A Matter of Balance (MOB) is a program designed for community-dwelling older adults with the intention to reduce fear of falling and encourage continued participations in social, physical and functional activities (Zijlstra, Tennstedt, Haastregt, Eijk, & Kempen, 2006). The intervention is delivered as part of a cognitive behavioural group session and aims to reduce fear of falling by increasing feelings of control over falls, increasing activity with realistic goal-setting, environmental modification and strength and balance through increased physical activity. T. Chen (2013) tested the effect of the MOB program on mobility, walking speed and postural control, as well as fall rates in community-dwelling older adults. The intervention group received eight 2-hour sessions once per week, whereas the control group discussed their functional test performance with the primary investigator at the first assessment and received exercise suggestions that they could partake in daily. The measures at the second assessment following the intervention showed that the total number of falls between the MOB program group and control group was not significantly different, and there was no difference in falls in either group from Time 1 to Time 2 ($F(1, 66) = 1.80$, $p = .185$). MOB did improve performance on tests of mobility ($F(1, 66) = 21.38$, $p < .001$), walking speed ($F(1, 66) = 21.14$, $p < .001$) and postural control ($F(1, 66) = 24.07$, $p < .001$) compared with comparison group from time 1 to time 2 .

A Cochrane review found little evidence with low certainty of results for behavioural modifications in visually impaired people, implying further research is needed in this group of older people before it can be determined if these results can be applied to visually impaired people (Jian-Yu et al., 2020) .

4.2.3 Medication review

Many medications are known to increase the risk of falls, so a potential intervention is to review the use of such medications and reduce them where possible. Indeed, according to a Cochrane review (Lesley D Gillespie et al., 2012) as well as a more recent literature review (Gray, Elsisi, Phelan, & Hanlon, 2021), gradual medication cessation is effective in reducing falls. It is difficult, however, to maintain long-term as in one of the reviewed studies many participants were using the medications again one month after the end of the intervention (Gray et al., 2021). Many studies struggle to implement and sustain medication changes, which may contribute to reporting no effect of intervention.

One paper that recommended medication changes as part of a falls prevention strategy reported an 81.1% adherence, with the reasons reported for not adhering to the suggestions concerning anxiolytics, sleeping medications or antidepressants were that the participants were unwilling to change or give up medications (Hansma, Emmelot-Vonk, & Verhaar, 2010).

4.2.4 Vitamin D supplements

A Cochrane review suggested that Vitamin D may reduce falls in older people who are deficient in vitamin D, but not those with normal levels (Lesley D Gillespie et al., 2012).

An Australian randomised controlled trial in 2,256 community-dwelling women over 70 years of age tested whether 500 000 IU of Vitamin D supplement administered orally once per year could reduce the risk of falls or fracture in participants considered at high risk of fracture (Sanders et al., 2010). The study was double-blinded and participants were randomly allocated to either receive an oral dose of Vitamin D, or a placebo.

Participants were sent 10 tablets via mail and instructed to take all tablets as a single dose. Each subsequent dose was sent annually to participants with the same instructions for three to five years after the first dose, and the last follow up was 12 months after the final dose. Falls were

reported via calendars which were completed by the participant and returned in the post. If a fall was reported, the participant was contacted via telephone and completed a questionnaire.

Across the study, there were a total of 5,404 falls reported, but surprisingly the participants who had been treated with vitamin D reported 15% more falls and 26% more fractures than the placebo group. This increased risk was most prominent in the first three months following the treatment each year, and the increase in fractures was in both falls-related and non falls-related fractures. It was the first study to report an increase in fall risk, and the second to report increased fracture risk, however it also used the highest reported dose of Vitamin D, whereas other studies that have reported decreased risk used lower dosages. The dosing schedule may also be an important factor, as the authors noted that other studies have found success with more frequent doses (e.g. every four months) and these studies have not reported harm.

High doses of Vitamin D are not an appropriate strategy for fall prevention, but there is little data since this study on the effect of lower doses on falls. Further research is needed to expand on the studies cited from before 2010 that used smaller and more frequent doses of vitamin D.

A double-blind, placebo-controlled study published in 2015 tested a smaller dose of Vitamin D (800IU daily dose), combined with exercise in 409 community-dwelling older women (Kirsti Uusi-Rasi et al., 2015). This study had four groups of participants: placebo only, placebo with exercise, Vitamin D only, and Vitamin D with exercise. There was no significant reduction in fall rate from either Vitamin D alone, exercise with placebo, or exercise and Vitamin D combined, but there was a significant reduction in the risk ratio for injuries resulting from falls for the participants in the exercise and Vitamin D group (RR 0.38, CI, 0.17-0.83). This reduction was also significant for participants in the exercise only group (RR 0.47, CI, 0.23-0.99). The authors also found that Vitamin D helped to maintain bone density across the 2-year follow-up period (Kirsti Uusi-Rasi et al., 2015).

4.2.5 Education

None of the studies on education-only interventions measured falls as an outcome. One such study did not measure falls, but following the intervention, people viewed their homes as less safe than before the intervention (Tiefenbachová & Zeleníková, 2019). Education is most often included as part of multifactorial interventions.

4.2.6 Medical factors:

Cardiovascular evaluation and treatment

There is a strong link between cardiovascular disorders and falls. A 2019 scoping review of cardiovascular evaluations and interventions reviewed seven papers (Luiting, Jansen, Seppälä, van der Velde, & Daams, 2019) and summarised the interventions into focusing on carotid sinus hypersensitivity (CSH) (four studies), sinus node dysfunction (SND) (two studies), or comprehensive cardiovascular assessment (one study). Of the four CSH studies, two reported significantly reduced falls rates following implantation of a pacemaker, while the remaining two showed no effect. The two SND studies followed participants for 12 months after pacemaker implantation to determine whether treating SND with pacemaker implantation would reduce fall risk. While both studies found a significant decrease across number of falls and fall injury, the authors of the review reported the second study to be suffering from selection bias and a number of confounding factors (Luiting et al., 2019). The last study reported a prospective pilot study from 2015 in people aged 65 and over who had suffered a fall in the past year, investigating cardiovascular screening and treatment as fall prevention (Jansen, de Lange, de Rooij, & van der Velde, 2015). The assessment was designed to identify known cardiovascular risk factors such as orthostatic hypotension, vasovagal syncope, structural abnormalities of the heart, arrhythmia, or carotid sinus syndrome. The cardiovascular

assessment was performed in addition to a multidisciplinary intervention with the aim of improving the overall efficacy of the intervention. Of the 15 participants, 10 were diagnosed with a cardiovascular condition, and seven of these participants' falls were attributed to the condition. Following the screening, 33% of participants experienced a fall, whereas all participants fell prior to the intervention. This study demonstrated that cardiovascular screening was feasible in the context of a multidisciplinary falls prevention strategy (Jansen et al., 2015), however more research is needed to investigate the efficacy of it as an intervention in a larger sample. The authors of the review concluded that, while there was a clear link between cardiovascular disorder and fall risk, more research is needed to evaluate the efficacy of a multifaceted cardiovascular assessment that include multiple types of cardiovascular intervention (Luiting et al., 2019)

Hip fracture screening

A recent study investigated whether hip fracture screening could reduce fall risk and incidence. This study was part of the UK-based SCOOP study in 12,483 women aged between 70 and 85 years. Participants were screened using the FRAX tool to calculate the 10-year probability of hip fracture. Participants reported their falls via postal survey periodically throughout the 60-month follow up period, where they indicated any falls that had occurred since the previous survey was completed. They also indicated their 12-month fall history at study entry. The FRAX tool was used to determine a risk category, which was then communicated to the participant's primary healthcare provider with advice to discuss treatment options for high-risk participants, increasing weight-bearing exercise, and decreasing alcohol use and smoking. The participants in the control group did not receive any information about fracture risk and received usual care. The SCOOP study reported a decrease in hip fractures overall, however this study revealed that this was not due to a decrease in fall incidence. There was no significant effect of hip fracture risk screening on fall incidence, indicating that the reduction in hip fractures seen in the SCOOP study is not mediated by fall risk (Condurache et al., 2020).

4.2.7 Exercise

Regular exercise can help to maintain physical functioning as a person ages by mitigating the loss of strength and muscle mass that is common in older age. A 2010 review of physiotherapist-led approaches to falls preventions included exercise interventions (Karinkanta et al., 2010). The authors conclude from their review of studies that exercise is the most cost-effective intervention to prevent falls and recurrent falls in community-dwelling older adults. However, they note that the efficacy of exercise interventions in preventing falls varies. Citing an earlier 2009 Cochrane review Karinkanta et al. note that the most important elements of exercise interventions are balance and muscle-strength training. Flexibility and endurance training are also beneficial. Falls and recurrent falls can be reduced by exercise interventions that contain at least two of these elements, particularly with the inclusion of balance and strength training. The authors also note that this type of exercise intervention can be carried out individually or in a group with evidence for supervised group exercise programmes providing a slightly better reduction in relative risk for falls.

Sherrington et al.'s updated systematic review included 54 randomised controlled trials of exercise interventions (Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). Their findings remained largely unchanged from their earlier meta-analysis with a pooled estimate of the effect of exercise interventions on the rate of falls of RR 0.84, (CI 0.77-0.91), or a reduction in fall rate by 16%. The greatest effects were found for programmes that included high to moderate challenge to balance training, and a higher dose of exercise (but did not include walking training) with a reduction in falls of 38%, (CI 27-46). The combination of high to moderate challenge to balance training, walking training and a higher exercise reduced risk by

21% (CI 11-30). The authors recommend that exercise interventions need to provide a moderate or high challenge to balance, be of a sufficient dose to have an effect (at least 2 hours per week) and be ongoing.

The ability to maintain balance following a postural perturbation has been suggested as a potential modifiable protective/risk factor for falls with evidence for its efficacy in reducing risk (Lurie, Zagaria, Pidgeon, Forman, & Spratt, 2013). Lurie et al. (2013) report findings from a pilot study in a community-dwelling sample (n=59, mean age 80.5 years (range 65 to 96)) designed to determine the feasibility of conducting a randomised trial comparing a multidimensional exercise programme including surface perturbation treadmill training (SPTT) to multidimensional exercise alone. Although the risk of falls was reduced in the SPTT group (RR 1.61, CI 0.53 – 4.88) as was the risk of falling with injury (RR 1.72, CI 0.27 – 11.14), these differences were not significant with the authors acknowledging that the study was underpowered. Longer-term studies with larger populations are recommended.

Although the efficacy of a range of exercise programmes is well documented, adherence to exercise regimes is often problematic. One study that recommended exercise as an intervention to prevent falls reported a low adherence rate of only 54.2% citing reasons such as not waiting to do the exercises, feeling as though they had improved and therefore did not need to continue the training, inability to commit time to it, or illness preventing further training (Hansma et al., 2010). Exercise programmes may not be appropriate or acceptable for particular populations of older adults. Dillon et al. note that few exercise intervention trials include participants with vision impairment and it remains to be determined whether findings can be generalised to older people with impaired vision (L. Dillon et al., 2018). The authors undertook focus groups with 19 older people with vision impairment (mean age 76 years (SD=8)) to explore the acceptability of different falls prevention programmes from their perspectives. Two key themes to emerge from the study were that interviewees did not attribute falls to vision impairment and did not see themselves as appropriate candidates for falls prevention programmes. The authors suggest that participants attribute falls to causes outside of the individual's control and underestimate the risk of falls in older adults. Participants were also reluctant to participate in falls programmes due to mobility and transport issues, competing priorities and possibly the stigma associated with being labelled as a falls risk. The authors make several suggestions on how to increase adherence to an exercise-based fall prevention programme in people with vision impairment, including tailoring programmes to individuals, and providing supervised support and motivation while being sensitive to participants' sense of identity and autonomy.

4.2.8 Strength and balance

Strength and balance, specifically in lower limbs, are independent of each other and should be tested and trained as complimentary elements, rather than being treated as one. A literature review revealed that balance training alone was effective in increasing balance, which was the measure of fall risk. Multifactorial interventions that include both strength and balance training tend to find significant improvements in dynamic balance measures, and reduced fear of falling (Hayes, 2018).

A recent review analysed the efficacy of high-velocity power training in improving physical function and balance performance and preventing falls in older adults (Tzurei Chen & Yoshida, 2021). The review of several primary studies and three systematic reviews concludes that power training can be more effective than strength training in enhancing physical function. The authors reviewed two studies for the impact of power training on balance and found evidence for an effect where balance performance was measured by biomechanical balance parameters (e.g., forward and lateral leaning assessment; and a computerized force platform). However, a systematic review and meta-analysis reviewed found little evidence for an effect of power

training on balance compared to strength training. With regard to falls preventions, one article was reviewed where a multimodal exercise programme, that included high-velocity power training, demonstrated improved functional performance in high-risk older adults. However, this improvement in function did not lead to a reduction in falls. Chen and Yoshida note an absence of published results to support the inclusion of power training in falls prevention programmes for community-dwelling older adults. However, the authors conclude that the evidence for the efficacy of power training to improve physical function in older frail adults is strong, Improvement in muscle strength, functional mobility, and balance (risk factors for falls) is a positive outcome for frail older adults. They suggest a minimal training duration of 12 weeks may be required for the training to reach its full effect in older adults.

As noted earlier the incidence of falls and recurrent falls in people with Parkinson's disease (PD) is very high (Allen et al., 2013; Fasano et al., 2017). Based on recently published evidence of the long-term (12 months) efficacy of balance training on reducing fall rates in PD patients, Wong et al. undertook a randomised trial of an 8-week physiotherapist-led multisystem balance training programme (4 weeks indoor and 4 weeks outdoor, 3 hours per week), with PD non-fallers and single fallers (mean age 61.0 years (SD=9.0) (Wong-Yu & Mak, 2019). The control group undertook upper limb activities. During the 12 months 41.5% of the experimental group and 30.8% of the control group experienced either non-injurious or injurious falls, however this difference was non-significant. There were fewer injurious fallers in the experimental group (RR 0.392, CI 1.35-38.33) compared to the control group. The authors conclude the balance training programme is a potentially effective intervention for reducing injurious fall risk among people with PD for at least 12 months post-training.

Otago Exercise Programme

The most well-known and most widely used fall prevention programme is the Otago Exercise Programme, a home-based programme developed at Otago Medical School. The programme involves 17 progressive strength and balance exercises and a walking plan and is recommended for community-dwelling adults capable of exercising without assistance (Martins et al., 2018). It can be performed by older adults in the home, outpatient, or community setting. The programme has been shown to be effective in reducing both the number of falls and falls-related injuries by 35% (Sherrington et al., 2011). Multiple studies and systematic reviews and meta-analyses provide evidence for its effectiveness (Martins, 2018).

A 2018 review focused on modified versions of the Otago Exercise Program (Martins et al., 2018). This review was not specifically focused on fall incidence as a main outcome, but some of the reviewed studies did report fall incidence as a secondary outcome. The modifications made to the Otago exercise program included additional exercises, delivery via DVD format, augmented reality or delivered as part of a group class. The authors conclude that modified formats of the OEP improve physical function (particularly balance) but is unclear whether modified versions are as effective as the original OEP. None of the reviewed studies that measured falls as an outcome reported a significant difference in falls incidence.

EnhanceFitness

EnhanceFitness is a community-based group exercise class led by qualified instructors. The classes are one hour long each and involve cardiovascular fitness, strength training, balance and flexibility. Greenwood-Hickman, Rosenberg, Phelan, and Fitzpatrick (2015) compared the EnhanceFitness program with Silver Sneakers, a benefit provided to older adults through Medicare health insurance which provides a full membership to participating fitness centres, of which there are more than 10,000 across the United States. Falls data was obtained through in-patient and out-patient records, and as such only captured falls that required treatment. Survival curve analysis revealed that consistent users (participated at least twice per year, every

year since enrolment) had the highest proportion of participants without a recorded fall needing treatment, compared with participants who only attended intermittently or non-users. When compared with non-users, consistent users of EnhanceFitness had a 26% reduced risk of falls requiring treatment, and intermittent users had a 13% decreased risk. Of the participants enrolled in Silver Sneakers, only the intermittent users showed a decreased fall risk of 7%.

The retrospective design of this study means that there may be important differences between participants who were consistent users of EnhanceFitness and Silver Sneakers, and those who were intermittent or non-users. Participation in either program was through voluntary self-selection, so the lowered risk in the consistent users of EnhanceFitness may be due to other factors that allowed them to continue to participate in the program, not the program itself. Additionally, the authors did not control for physical activity outside the two programs, and the lower limit for being classified as a consistent user was low at only two uses per year.

Stroll Safe

Stroll Safe is a seven-week outdoor fall prevention program consisting of weekly 90 minute sessions in a group setting (Chippendale, 2019). The programme is split into modules, each addressing different components of outdoor fall prevention such as the built environment, social environment, neighbourhood conditions and personal factors. Each session incorporates a presentation, group discussion, problem solving and action planning of behaviours each participant would implement each week. Two of the sessions also include mobility training and practice of the concepts learned in the modules, and the final session is a review (Chippendale, 2019)

A 2019 study evaluated the feasibility of the Stroll Safe Outdoor Fall Prevention program in 24 over 55-year-olds. The authors reported increased use of fall prevention strategies and a reduction in number of outdoor slips, trips and falls in both the control group and the intervention group, but more so in the Stroll Safe group (Chippendale, 2019)

Tai Chi

Tai Chi is a Chinese martial art from the thirteenth century that incorporates mind-body principles to encourage strength, endurance, mobility and balance through functional movement patterns, originally used for training young warriors (Hallisy, 2018). It is usually run as group classes in the community. There are many different forms and variations of Tai Chi, however many studies use simplified versions that are easier for participants to practice (Wooton, 2010).

An integrative review from 2010 of articles published between 1998 and 2009 focused on the impact of Tai Chi on falls and balance in adults over age 55 (Wooton, 2010). Overall, the authors concluded that most studies on Tai Chi reported improved balance and functional independence with some evidence for decreased fear of falling. Of the 22 reviewed studies, five also reported a decrease in falls following the Tai Chi interventions (Wooton, 2010). The authors of this review suggested that an important factor in determining the efficacy of a Tai Chi intervention is the length of program, and the reviewed interventions varied in length from 3 weeks to one year. A more recent literature review from 2018 reviewed meta-analyses and systematic reviews about Tai Chi interventions published from 2012-2017 and revealed that in order to reduce fall incidence directly, participants needed 50 hours of Tai Chi over six months, broken into 60 minute sessions, twice per week (Hallisy, 2018).

An Australian RCT from 2015 tested the effect of a modified Sun style Tai Chi intervention on falls in people aged 70+ classed as preclinically disabled (Day et al., 2015). Participants in the intervention group took part in a 48-week modified Sun style tai-chi exercise program, with 60-minute group classes twice per week. The participants in the control group took part in a

seated group-based flexibility exercise program for the same period of time, also twice per week. The authors reported a higher proportion of participants dropping out of the study in the intervention group and found that these lost participants tended to have weaker quadriceps and worse scores on the Timed Up and Go test. There was no evidence of modified Sun style tai chi preventing falls in this group of people, which may in part be due to the lower attrition rate or lack of intervention intensity (Day et al., 2015). An earlier study cited in Wooton (2010) also reported no effect of Sun style Tai chi on fall incidence, but that it was effective in improving fall efficacy.

Yoga

There is little evidence of the effect of yoga interventions on fall incidence, but there is some evidence that it may improve balance and fear of falling, both of which are risk factors for falls. Nick and colleagues tested participants' fear of falling and balance scores before and after an instructor-led yoga intervention, consisting of twice-weekly one-hour classes for eight weeks (Nick, Petramfar, Ghodsbin, Keshavarzi, & Jahanbin, 2016). The authors reported a significant increase in balance ($P < .0001$) and a significant reduction in fear of falling ($P < .0001$). This study was small, however, and only selected 40 participants who scored low on the Berg Balance Scale, and Modified Falls Efficacy Scale, indicating an increased risk of falling and a fear of falling (Nick et al., 2016).

Saravanakumar, Johanna Higgins, Jane van der Riet, Marquez, and Sibbritt (2014) conducted an RCT in an Australian residential aged care facility that included a 14-week yoga intervention program as part of a feasibility study. Participants took part in classes twice per week, for 30 minutes each session, whereas the control group did not take part in any programme and were encouraged to participate in weekly physical activity and group activities through the aged care facility. The primary outcome for this study was balance, but falls were also recorded for 6 months either side of the intervention, and during the 8-week intervention period. While the intervention group did show a trend towards a lower fall incidence rate (9 recorded falls in the yoga intervention group compared with 11 in the control group), this difference was not significant. The yoga group did show an improvement in balance, whereas the control group's balance score decreased, however this was also non-significant. This study had a very small sample size, with only 11 participants in each group, which is likely to have contributed to the lack of significance in results. This study was a pilot study, therefore further research is required on the possibility of yoga as a fall prevention intervention.

Aquatic exercise

Most literature focuses on reducing known risk factors rather than falls themselves. The most recent literature review (Martínez-Carbonell Guillamón, Burgess, Immins, Martínez-Almagro Andreo, & Wainwright, 2019) focused on the effect of various aquatic exercise programs on strength, balance, flexibility, endurance, agility and speed. Overall, the aquatic exercise groups had improved balance, flexibility and strength, all of which are linked with lowered risk of falls, however much of this evidence was described as being of low quality and many of the interventions were not described in enough detail to truly compare them (Martínez-Carbonell Guillamón et al., 2019).

Since this review was published in 2019, there have been 2 further studies published around aquatic exercise and falls, however neither use falls as an outcome and only link aquatic exercise to changes in functional parameters (Arnold, Faulkner, & Gyurcsik, 2011; Saleh, Rehab, & Aly, 2019). A protocol published in 2020 proposed a 16-week aquatic exercise intervention and will measure a variety of physiological outcomes, as well as the occurrence of falls over a 22-week period, in a group of over-65s (Ferreira et al., 2020). At the time of this review, however, results have not yet been published.

Dancing

There are few studies that measure the rate of falls following a dance intervention. One study which did measure fall occurrence (Merom et al., 2016) found no significant difference between the control group and the dance intervention group. There were several confounding factors in this study which may have contributed to the lack of significance, e.g., baseline differences between each group. The dance intervention group were more likely to be classed as moderate- to high-risk of falling, were older and in poorer health than the control group. The intervention itself may have contributed, as it may have increased the participant's confidence, leading to increased activity, and therefore more falls. Physical activity increased in both groups, but more so in the dance intervention group. Additionally, those in the intervention group who had reported multiple falls prior to the intervention experienced significantly more falls than those in the control group who had reported multiple falls before the intervention, suggesting that the intervention is inappropriate for older people at high risk of falls.

4.2.9 Technology-based

Virtual reality training

Mirelman et al. (2016) highlighted the need for fall prevention to incorporate both cognitive and motor aspects, which may be achieved through the use of virtual reality technology. Community-dwelling older adults participated in a non-immersive virtual reality (VR) augmented-treadmill training programme, which was compared with treadmill training without VR. The intervention was delivered in a 6-week training programme with a 6-month follow up. Participants trained 3 times per week for the duration of the programme, for 45 minutes per session. The participant's movement was recorded with a camera, and their footsteps were then projected onto a screen in front of them within the virtual reality environment. The virtual reality environment presented obstacles, pathways and distractions to increase cognitive load which the participants responded to by adjusting their steps in real time. The training sessions increased in difficulty throughout the training program, with increased treadmill speed, size and frequency of obstacles, and duration of walking. The results indicated that both VR treadmill training and treadmill training without VR reduced the number of falls in the 6-month follow up, but only the reduction in the VR treadmill training group was significant. The VR treadmill training group also experienced greater improvements in secondary outcome measures, particularly in gait and balance measures. The VR treadmill training group had increased endurance, obstacle clearance and quality of life at the 6-month follow up than the treadmill training without VR group.

Wii Fit

The Wii is a gaming system developed by Nintendo, and the Wii Fit is a balance board and software that combines exercise with gaming (Williams, Doherty, Bender, Mattox, & Tibbs, 2011). Training using Wii Fit has been shown to improve balance, walking speed and confidence in older adults (Agmon, Perry, Phelan, Demiris, & Nguyen, 2011; Whyatt, Merriman, Young, Newell, & Craig, 2015) suggesting that it may be useful as a fall prevention strategy.

A randomised control trial in frail community-dwelling older adults compared a 12-week Wii Active exercise intervention with gym-based exercise intervention (Kwok & Pua, 2016). The intervention group received 20 minutes of gaming exercises using the Wii Fit as part of a weekly one-hour long session. The control group participated in weekly one-hour gym classes incorporating cardiovascular, balance and strength training using free weights and gym equipment. Both groups received safety advice for their home at the start of the intervention and were encouraged to continue with home exercises incorporating balance and resistance band exercises. Participants were followed up at 13 weeks and 24 weeks. While the primary

outcome in this study was fear of falling, fall incidence data were collected for a year as a secondary outcome. There was no between-group difference in fall rate or gait and balance outcomes, but both groups showed an overall improvement in measures of gait and balance, and knee extensor strength. The Wii Fit group had a significant long term improvement in fear of falling (Kwok & Pua, 2016).

Vibration training

Vibration training typically involves standing on an oscillating platform for a period of time, and sometimes performing exercises while standing on the platform (Karinkanta et al., 2010). The vibrations can vary between specific devices in terms of speed and intensity, which in turn varies the reactive response needed by the participant. Vibration training, however, may be deemed unsuitable for many older adults due to certain medical conditions such as bladder problems or kidney stones, hernia, rheumatoid arthritis, cardiovascular disease or diabetes mellitus, excluding many people at risk of falls from being able to participate in the intervention (Karinkanta et al., 2010).

A physical therapy-focused review of randomised, controlled trials found evidence of vibration training improving lower body muscle performance and balance in older adults, and one RCT found evidence that vibration training may reduce fall incidence in older women (Karinkanta et al., 2010).

A New Zealand-based RCT tested whether vibration training improves falls risk and functional ability in older persons (Parsons, Mathieson, Jull, & Parsons, 2016). This study focused on falls risk and known risk factors, rather than actual fall incidence. There was no difference in physiological measures (vision, balance, reaction time, proprioception, strength), which were the primary outcome measures in this study, but there was a significant improvement in Functional Independence Measure (FIM) scores and perceived fear of falling, indicating vibration training increased functional ability and therefore may assist in reducing fall risk (Parsons et al., 2016).

Buckinx et al. (2014) tested the impact of whole-body vibration training in nursing home residents. The participants took part in a 6-month exercise program using a vibration platform; exercises were performed three times per week with at least 1 day of rest in between. The control group was not instructed to do anything different and to continue with usual care. The participants' risk of falls, functional skills and motor skills were assessed at baseline, 6 months, and 12 months after the intervention. There were no significant differences between groups on any outcomes. Specifically there was no significant difference in the frequency of falls between the control group or intervention group across the 12-month period. This study, however, was subject to several important limitations. The sample size was small (only 31 participants in each of the intervention and control groups), which the authors stated lacked statistical power. Additionally, the two groups differed in measures of BMI, cognition and the proportion of males to females. Falls were recorded by the nurses in the nursing home, but not by the participants themselves, which may have missed some of the more minor falls that did not require assistance. The amount of time of actual vibration per session totalled 1 minute and 15 seconds, which the authors noted may have been too short. A further stated limitation was that the intervention group walked "all the way up to the physiotherapy room three times per week" (Buckinx et al., 2014, p. 375), whereas the control group did not have any change to their physical activity. The authors did not specify how far the distance was to the physiotherapy room, or if there were any flights of stairs involved, but it is possible that the walk may have influenced the rate of falls, rather than the vibration intervention.

4.2.10 Footwear

The type of footwear an older person chooses to wear often changes throughout the day with various activities and needs, but some types of footwear may decrease balance, thus increasing fall risk. Inside the home, it seems that falls are probably more due to intrinsic risk factors such as functional ability than can be attributed to footwear. Outside the home, environmental factors such as the type of surface, temperature or presence of snow, or individual factors such as gait characteristics or physiology tend to be more responsible for falls than the footwear itself. A 2010 review reported that one RCT significantly reduced the rate of falls during icy conditions via anti-slip shoe devices (RR 0.42, CI 0.22–0.78). These anti-slip devices were reported to be affordable and well-adopted by participants (78% compliance rate) so may be very useful as an intervention for adults living in areas prone to ice (Karinkanta et al., 2010).

A more recent review of 41 articles focused on the role of podiatrists in reducing fall risk, however not all of the included articles included falls as an outcome. This review looked at the role of podiatrists in both fall risk assessment and interventions (Rosenblatt, Girgis, Avalos, Fleischer, & Crews, 2020). One study compared different types of indoor footwear and found that balance and gait could be improved in older women when wearing shoes with Velcro fastening, an enclosed heel and firm sole, whereas backless slippers did not improve gait or balance (Menz et al., 2017, cited in Rosenblatt et al., 2020). Since gait and balance are risk factors for falls, the authors concluded that improvement in these areas due to the footwear could lead to a reduced fall risk. The authors also reported the results of a multifactorial intervention including foot orthoses, which reduced fall rate by 36% (Spink et al., 2011, cited in Rosenblatt et al., 2020). There were issues with maintaining long-term use of the orthoses despite participants reportedly being highly satisfied with the intervention; six months after the intervention, only 69% of participants were still using the orthoses and 54% using the prescribed footwear. The participants who were still using the orthoses tended to be younger with less fear of falling, implying further attention was needed for more at-risk older adults. The authors of the review noted that none of the recent studies used custom orthoses, rather they used prefabricated ones. A previous review (Hatton et al., 2013, cited in Rosenblatt et al., 2020) reported custom orthoses being beneficial for balance and gait performance, however further research is needed on custom orthoses and fall rate.

Rosenblatt et al. (2020) also reported that foot and ankle exercises alone may be useful in preventing falls, in that there is evidence that programs involving specifically foot and ankle exercises improve balance and flexibility. Given that foot pain is documented as a risk factor for falls in older people, addressing foot pain may be an effective fall-reduction intervention. Scores on balance measures improved in one reviewed study that treated a specific form of foot pain, but another found that using tape as a treatment improved some balance scores but reduced mobility. In a RCT study reviewed by Rosenblatt standard foot care once per month improved strength in Japanese older adults, which may reduce fall risk due to improved strength.

A Cochrane review found that footwear assessment, insoles and the addition of specific exercises targeting the feet and ankles was effective in reducing the number of falls in a group of people with foot pain, however the number of people who experienced falls was unchanged (Lesley D Gillespie et al., 2012).

4.2.11 Multifactorial interventions

A multifactorial approach is based on the concept that falls are a result of an accumulation of risk factors and medical problems, thus requiring an intervention that addresses the multitudes of contributing factors to a person falling (Karinkanta et al., 2010). A single intervention would require an exceptionally high level of efficacy to have as much of an impact as a well-designed

multifactorial intervention would (Buckinx et al., 2014). Multifactorial interventions involve an assessment of the fall risk of each participant, and different individual interventions are recommended based on each person's unique needs. Multifactorial interventions that combine home modifications, exercise (either through group or individual sessions) education about fall prevention strategies and recommendations for assistive devices tend to be the most successful interventions in reducing fear of falling and the number of falls in older adults (Chase et al., 2012).

Hansma et al. (2010) used a standardised multifactorial falls assessment to assess the fall risk of participants with a history of falls and examined how carrying out this assessment and the subsequent recommendations could affect the rate of falls and fear of falling in the 12 months following assessment. The assessment evaluated health measures, home situation, fear of falling, mobility, dependence in performance ADLs, depression, cognition, medication use, physical health, gait and balance. Risk factors were established from the collected data and the results were discussed with the participants and their doctors to allow for referrals and suggested interventions. The participants were then followed up via phone to determine the effect of the falls risk assessment. The assessment identified risk factors and made it possible to make recommendations regarding appropriate interventions. The most common recommendation was to adjust medication use, followed by implementing an exercise routine. The authors reported a 70.9% decrease in fall incidence in the year following the intervention from a mean of 3.78 +/- 4.66 falls/year per participant to a mean of 1.10 +/- 1.86 falls/year per participant ($p < .001$). There was also a significant decrease in fear of falling in 86.8% of participants, from 5.62 to 3.88 out of a maximum of 10 ($p < .001$). This study, however was relatively small and relied on participant's memory in recalling the number of falls during the follow-up time, which people tend to underestimate (Hansma et al., 2010). A more reliable way of recording number of falls following the intervention would have been to record them on calendars, as other studies have.

In a 2010 review of 15 trials, multifactorial interventions were effective in reducing the rate of falls among older adults living in the community s (RR 0.75, CI 0.65–0.86) (Karinkanta et al., 2010). The authors concluded from a sub-analysis of a cited Cochrane review that key factors in a multifactorial intervention included using a multidisciplinary team (RR 0.60, CI 0.51–0.72) and introduction of an exercise routine (RR 0.85, CI 0.77–0.95). Three of the studies included in this review which included these two key factors also reported a reduction in hip fractures s (RR 0.48, CI 0.24– 0.98).

A systematic review of multifactorial interventions published up until 2019 (S. H. Lee & Yu, 2020b) reported that multifactorial fall prevention interventions reduced both fall rates and the number of people experiencing falls among older participants. Fall rates were significantly reduced in high risk and healthy adults but not in frail older adults. High risk older adults were categorized as people with a history of falls or presented with risk factors for falls or defined as being at high risk of falls based on the screening survey. Frail older people were categorized as participants 80 years and older regardless of their fall experience or defined as frail based on the scores in the respective study. Only three studies included frail participants, whereas most studies used high risk participants. Healthy older adults were participants with a low risk of falls. The key factors in multifactorial fall prevention were exercise and environmental modifications. This was evidenced by the discovery the interventions that did not contain an exercise component had no significant effect when compared with usual care and, likewise, interventions not containing environmental modifications also had no significant effect when compared with usual care. Another key factor revealed by this review was the difference between active interventions and referral-based interventions. Active interventions actively

assess the risk factors and resolve falls-related problems directly, whereas referral interventions only provide referrals to other services or information for which the participants can then seek out. Active interventions were more effective and reducing fall risk across the reviewed studies.

Purely recommendation-based multifactorial interventions tend to be less effective than ones which actively provide interventions as part of the study. A multifactorial assessment was carried out by professionals with specific training in falls assessment (Jenkyn, Hoch, & Speechley, 2012). Any potentially modifiable risk factors were addressed, and recommendations were made including referrals to other health professionals but did not include any treatment or on-going monitoring. This intervention was compared with usual community-based primary care, in which the primary care providers for the participants were sent a letter informing them of their patient's participation in the study and listing the identified risk factors, which gave the opportunity for ongoing usual care to be modified to address the fall risks. The authors reported no statistical difference in the number of falls between the intervention and usual care groups.

A multifactorial intervention study in 616 community dwelling adults over age 65 comparing interventions with and without exercise divided participants into two groups (H.-C. Lee et al., 2013b). The intervention group received a multifactorial intervention incorporating exercise classes, medication review, health education, environmental modification and referral to specialists. The control group received only health education brochures along with medication review and medical referrals but did not receive direct exercise training and structured health education classes. The exercise component of the intervention was a series of small, group supervised exercise training led by physical therapist or trained instructor. Classes focused on strength, balance, cardio-respiratory endurance and flexibility and ran for 50 to 60 minutes at a time once per week for eight consecutive weeks. The participants also received home exercise recommendations in addition to the classes. Falls were measured as the proportion of participants who experience a fall during the 12 months following the intervention and were recorded monthly via phone call to the participant. Across the 12 months after the intervention there was no difference between the intervention group and the control group in terms of proportion of participants who fell at least once. The intervention group did experience reduced overall fall risk and improved functional performance at the three-month follow-up. The overall fall rate of 28% across both groups and the 12-month follow up was lower than the authors expected, which may suggest that the fall incidents reduced in both groups due to the common interventions between them. Additionally, the intervention group had a high rate of previous falls; the authors observed that there was a significant decrease in fall incidents from 41.2% in the year prior to 27.5% in the 12-month follow-up fall intervention group. The control group had a lower initial fall rate of 29%, which reduced to 27.7% in the 12 months following the intervention which was non-significant. Given that previous falls are a strong predictor of fall rate (Poss & Hirdes, 2016), this baseline difference between the two groups could disguise any positive affect of the intervention. The intervention also appeared to be more effective for participants in the intervention group who were classed as being of high risk, who had larger improvements in functional outcomes, whereas low risk adults did not experience the same benefits implying that high risk older adults could benefit most for a programme such as this.

Formosa, Burkett, Fawcett, Burke, and O'Leary (2014) conducted a multidisciplinary falls risk assessment intervention in 51 participants (aged 77.5, SD=8.8 years, 65% female) including measures of nutrition, walking speed, falls efficacy, blood pressure, prescribed medications and physiological measures. Based on the results of the risk assessment, medical, environmental, exercise, and community-based recommendations were provided to the

participants. At the 6-month follow-up assessment, the authors reported a 64% reduction in the number of falls, a 75% reduction in injuries and a 77% reduction in need for medical attention.

Kittipimpanon, Amnatsatsue, Kerdmongkol, Jarupat Maruo, and Nityasuddhi (2012) reported a reduction in falls following implementation of a community-based multifactorial fall prevention program over 10 months in a Thai community with a high rate of falls. The program involved a fall education program delivered once per year, a multifactor risk assessment, an exercise and balance group class, twice-yearly home visits, medication review, and a fall management system for monitoring the occurrence of falls throughout the program. Two (7.14%) of the 28 participants fell during the program, compared with nine (34%) prior to the program. The authors also reported a significant increase in overall fall prevention behaviours, strength, balance and gait.

A Japanese study tested the efficacy of two community-based fall prevention programs in 24 senior centres. The first program implemented at eight of these centres involved a single visit from a multidisciplinary team for a fall prevention lecture and fall risk assessment and feedback. The second program was implemented at 16 senior centres and was a comprehensive, year-round program with visits by the multidisciplinary team every three months. Overall, there was a significant decrease in falls for both groups, however there was no difference between the single-visit intervention group and the comprehensive, year-round intervention group. The authors revised the intervention and developed a modified intervention based on the single-visit program. Over the course of ten years, the programs significantly reduced falls and were well-accepted in the community, with most of the senior centres requesting the team return every year and almost all users of the senior centres participating (Otaka, Morita, Mimura, Uzawa, & Liu, 2017).

4.2.12 Multiple or multicomponent interventions

Multicomponent interventions are similar to multifactorial interventions in that they target a number of different risk factors in order to reduce fall rate. In a multicomponent intervention however, all participants are subject to the same multiple interventions, rather than being specifically targeted to each participant based on their needs as they are in multifactorial interventions.

In their review, Karinkanta et al. (2010) noted that most multicomponent interventions contain an exercise component. One of the cited studies implemented an intervention consisting of exercise, education and home safety, resulting in a 31% reduction in falls (Clemson et al., 2004 cited in Karinkanta et al., 2010). A second study highlighted the efficacy of exercise as part of the intervention, as there was an 81% drop in falls when exercise was combined with Vitamin D and calcium supplements, compared with participants who only received the supplementation intervention without exercise (Swanenburg et al. cited in Karinkanta et al., 2010). In one of the cited studies, the greatest reduction (33%) in fall incidence occurred for participants who received home modifications, visual correction and exercise together, whereas participants who received an exercise-only intervention showed a lesser reduction in fall incidence (18%) (Day et al., 2002, cited in Karinkanta et al., 2010).

A multicomponent fall prevention intervention set in nursing home residents in Iran combined education for residents and health care providers, environmental modifications and a 4-month physical exercise program (Najafi-Ghezeljeh, Ghasemifard, & Jafari-Oori, 2019). The educational component of this intervention involved lectures and educational booklets containing information about fall risk factors, mobility aids, and strength, balance and flexibility exercises. The exercise program involved group classes run three times per week in the mornings for four consecutive months. The classes incorporated strength, flexibility and

balance improving exercises including turning, standing from a sitting position and walking. For the environmental modification component the nursing home was assessed for environmental risk factors for falls by the main researcher using a standardized environmental risk assessment tool (van Schooten et al, 2015, cited in Najafi-Ghezeljeh et al., 2019). The fall rate significantly decreased following the intervention (2.40 ± 0.93 to 0.20 ± 0.55). Additionally, measures of fall risk were also significantly improved. Specifically, Timed-up-go scores significantly decreased; depression scores significantly decreased, and measures of mobility increased. The authors attributed the success of the intervention to addressing balance, depression, education and environmental modifications at the same time, whereas previous studies had focused on physical exercise, diet, and education. This aligns with other research on multiple or multifactorial interventions, many which have found success when the intervention involves home modifications (S. H. Lee & Yu, 2020b), and improves balance, as poor balance is a strong predictor of falls (Cuevas-Trisan, 2017; Salzman, 2010). There is plenty of evidence for balance interventions reducing the risk of falls in older people (Sherrington et al., 2011).

InSTEP

The InSTEP (Increasing Stability Through Evaluation and Practice) program is a multicomponent intervention developed by the Fall Prevention Centre of Excellence (FPCE), an interdisciplinary fall prevention-focused centre in California. Kramer et al. (2014) compared the effects of the InSTEP program on fall risk at three different intensity levels (low, medium, high). At each intensity level, the program consisted of physical activity, medical risk assessment, and home safety. In the low intensity group, participants were prescribed a 12-week exercise program including balance, strength and flexibility training to be completed at home. The participants were given a printed copy of the program, as well as video demonstrations and practice sessions. For the home modifications, the low-intensity participants completed a self-administered risk assessment checklist for their home and met with research staff to plan up to five modifications and receive information about funding and where to source resources. For the fall risk assessment, low intensity participants completed a self-administered checklist and were encouraged to discuss the results with the primary care provider.

The medium intensity group took part in a 12-week exercise program, consisting of two 60-minute structured group classes per week, which included balance, strength and flexibility training taught by a trained instructor. The program was developed by FPCE for use in the InSTEP program. They also received an in-home assessment from a social worker who worked with the resident to make an action plan including up to five modifications and were referred to an agency to provide up to $500 worth of modifications, paid for by FPCE, and follow-up via phone call. The social worker also completed a fall risk checklist and formally recommended that the participants discuss the findings of the checklist with their primary care provider.

The high intensity group took part in a 12-week exercise program, also consisting of two 60-minute group classes per week. The classes were the FallProof program taught by a trained and certified instructor and focused on progressive balance, strength and gait. The participants were also given a home exercise program to supplement the FallProof program, provided via DVDs. The home assessment was conducted by an occupational therapist, who assisted the participants in creating an action plan of up to five modifications and were referred to an agency to provide up to $500 worth of modifications, paid for by FPCE, with follow-up via home visit. Fall risk screening was conducted by a physician and formal recommendation that the participants discuss the findings of the checklist with their primary care provider.

Participants self-reported their falls during the 12-month study duration using a falls diary. At baseline, participants were asked to report any falls they had had in the previous 12 months. Of the 171 participants with complete data, 53.2% of participants reported at least one fall. Overall, there was an 18.1% decrease in the number of participants reporting a fall during the 12-month study duration (OR 2.7, CI 8.6, 27.7) and a significant reduction in the total number of falls reported from 169 at baselines to 117 ($T = 30$, $z = 3.263$, $p = .001$, $r = -.25$). There was also a significant 9.9% decrease in the number of participants self-reporting more than one fall within the 12-month period (OR 2.5, CI 2.4, 17.5). The authors also reported improvements in measures of function and perception immediately after the intervention, but these improvements were not maintained at later time points. When the three levels of InSTEP were compared, all levels led to a reduction in falls rate between baseline and the final follow-up, but only the 24.5% decrease in the medium intensity level was significant (OR 5.7, CI 8.8, 40.3) (Kramer et al., 2014).

5 Evidence synthesis

Although some falls are caused by a single factor, many result from a combination of multiple factors. As a result, a wide variety of interventions have been developed to reduce fall rate among older adults. These preventative strategies range from interventions targeting specific risk factors to those that take a holistic multifactorial approach targeting multiple intrinsic and extrinsic risk factors.

5.1 Interventions targeting Person-specific / Intrinsic Factors

5.1.1 Demographics

Risk factors, such as age, gender and ethnicity are not modifiable, however a falls risk assessment can include these factors to help identify individuals with an increased risk of falls making it possible to recommend appropriate interventions. Although theoretically modifiable, no interventions were identified that directly targeted socioeconomic status or geographical location to reduce falls.

5.1.2 Systems

System-based risk factors include gait, balance, mobility and physical activity, factors which are typically included in falls risk assessments. Identifying and treating any underlying neurological or psychiatric conditions, orthopaedic problems or medical conditions that may be contributing to deficits in these areas is key. Exercise interventions often target or indirectly target one or more of these factors. Exercise appears to be one of the most cost-effective interventions to prevent falls and recurrent falls in community-dwelling older adults, but the efficacy of exercise interventions varies. The most consistently effective elements of exercise interventions are balance and muscle-strength training. Flexibility and endurance training are also beneficial. Exercise must be challenging (but safe in this age group), of suitable duration, and ongoing. The most well-known and most widely used exercise-based fall prevention intervention remains the Otago Exercise Programme. There is considerable evidence for its efficacy in reducing falls. Mobility and physical activity have been shown to be improved by A Matter of Balance programme (but not falls rate). The Stroll Safe programme includes mobility training and has been shown to reduce slips and falls. Tai Chi has been effective in improving balance and functional independence and reducing falls (though the evidence is not overwhelming). There are many versions of Tai Chi and modified versions that are easier for participants to practice are common. Evidence suggests that to be effective in reducing falls participants need undertake regular practice over reasonably long periods of time. There is mixed evidence for the impact of power training (over strength training) on falls rates, however there is clear evidence that it enhances physical function in older frail adults. Yoga interventions may improve balance and fear of falling, both risk factors for falls, but there is little evidence of the effect on the incidence of falls. Aquatic exercise may improve balance, flexibility and strength, but there is no reported evidence for an effect on falls. Few studies measured falls following a dance intervention. There is some evidence for increased physical activity levels, however dance intervention is inappropriate for older people at high risk of falls.

The use of technology in exercise training is receiving more attention. Virtual reality training with treadmill training has shown improvements in gait and balance and a reduction in falls. Wii Fit has been shown to improve balance, walking speed and confidence in older adults, however the one study reviewed found no reduction in fall rate compared to controls.

Exercise programmes may not be appropriate or acceptable for particular populations of older adults, for instance, those with limited mobility or visual impairment, and thus should be tailored to the strengths and weakness of individuals. Group and community-based exercise programmes may be slightly better at reducing risk for falls than individually based programmes. The inclusion of exercise and balance training in a multifactorial intervention seems appropriate, however it should be noted that adherence to exercise regimes is often problematic and they are not appropriate for those already at high risk of falls.

Sensory system deficits increase the risk of falls and are potentially easily modifiable falls risk targets. Appropriate screening of vision and hearing can be included in a falls risk assessment (either through direct assessment or from administrative records). Correcting poor vision and hearing may reduce falls related to physiological changes associated with ageing and ill health. Reducing the disability associated with these sensory impairments may also indirectly reduce falls risk by increasing participation in everyday activities and reducing social isolation (a further falls risk factor).

Home modifications may assist in reducing the impact of sensory deficits on falls and may be preferred by those with visual impairment. For instance, simply removing hazards like rugs that may be difficult for the visually impaired to navigate. However, such modifications should be individualised and take into account how the sensory impaired interact with their home environment. For instance, removing a home risk may increase falls risk by interfering with long-term behavioural patterns associated with familiar sights and sounds in the home.

Cognitive impairment and dementia are clear risk factors for falls in older adults. Unsurprisingly no interventions to directly target these factors to specifically prevent falls were identified. Geriatric screening and falls risk assessment routinely include items to measure or assess cognitive function. A wide range of interventions may be targeted at falls within these groups, (particularly within aged residential care), to improve quality of life, and indirectly falls risk (Gitlin, Hodgson, & Choi, 2016). Falls risk may be addressed by multifactorial interventions within these populations, however whether specific falls prevention interventions are generalisable to cognitively impaired populations requires further research. Future research that aims to assess interventions designed to maintain or improve cognitive domains in older adults could include falls as an outcome variable.

5.1.3 Behavioural Factors

Physical activity is a key protective factor against falls in older adults. Interventions targeted at gait, balance and mobility through exercise are reviewed above. Multifactorial interventions commonly include exercise programmes facilitated through individual or group sessions with the target of improving physical activity and function. There is evidence that interventions that do not contain an exercise component have little impact on fall rate over usual care. Exercise alone may also reduce fall rate.

No interventions were identified that specifically targeted alcohol consumption in order to reduce falls.

5.1.4 Medical and Health Characteristics

The review highlights the role of several chronic health conditions that are associated with falls including Parkinson's, stroke, cardiovascular disease, arthritis, incontinence, and diabetes, although specific interventions that target characteristics of the condition or the disease process itself to prevent falls are rare. The disparities in fall rates between people with chronic disease

and those who don't underlines the heterogenous nature of community-dwelling older adults. These findings demonstrate the complex interaction between health characteristics and falls in older adults, emphasising the importance of integrated care for these health issues. Effective management of chronic health conditions serves to decrease falls risk. For instance, treating underlying CVD processes (e.g., implantation of pacemaker) showed benefits in reducing falls. By reducing the impact of symptoms that contribute to falls risk through a person-centred care approach and strategies such as medication monitoring, health professionals can promote function and independence. Interventions that focus on maintaining or improving physical function in those with chronic conditions will also contribute to a reduction in falls risk. Falls assessment screening should include a review of relevant health conditions in older adults. For instance, the effectiveness of a cardiovascular screening as part of a multidisciplinary fall prevention strategy was demonstrated in a small study. Any falls assessment should include a medical review with particular emphasis given to the interaction between multi-morbidity and medication use.

Interventions undertaken with the general population of older adults may be generalisable to targeted population groups. For instance, balance training which is demonstrated as an effective falls reduction intervention in older adults, has also been shown to reduce the rate of injurious falls in Parkinson's patients. However, some interventions may not be suitable for those with particular chronic conditions. For instance, vibration training is not appropriate for those with a wide range of conditions including previous fractures, acute rheumatoid arthritis, and serious cardiovascular disease (although it should be noted that the evidence for the efficacy of vibration training in reducing falls is weak).

One of the most predictive falls-related risk factors is a history of falls. While this is inherently a retrospective risk factor that should be included in any risk assessment, falls interventions may reduce recurrent falls. Occupational therapist-led home modifications have been shown to reduce falls rate in those with a history of falling. Multifactorial interventions appear to reduce fall rates in high-risk groups (including those with a history of falls), particularly where they include exercise and environmental modification components.

No specific interventions were found that targeted foot problems to reduce falls, however those with foot pain may benefit from a footwear assessment and exercises targeting the feet and ankles.

5.1.5 Psychological Conditions

No intervention studies in the review timeframe were found that addressed sleep quality, loneliness or falls risk awareness.

Depression is common in later life and a risk factor for falls. No intervention studies were identified that targeted depression in older adults to prevent falls. One reviewed study showed a decrease in depression scores (and fall rate) after a multicomponent fall prevention intervention in a nursing home. Identifying (through falls risk assessment) and treating depression in older adults should contribute to a reduction in falls in this population. As the association between depression and falls may also be bidirectional, with falls leading to avoidance behaviours, social isolation, lower self-efficacy and subsequent depression, interventions that address social engagement in older adults may also be beneficial.

Interventions to reduce the fear of falling should be designed to encourage continued participations in social, physical and functional activities. The evidence in the review for

interventions to reduce the fear of falling was slight. Home modifications (lead by an OT) and a programme based on cognitive behaviour therapy group sessions did not lead to a reduction in fear of falling. Active interventions appear to be more successful with a vibration training intervention and a Wii Fit exercise programme showing a significant improvement in fear of falling. When included in multifactorial interventions exercise can also reduce fear of falling.

5.2 Interventions targeting Environmental / Extrinsic factors

5.2.1 Medication Use

Several classes of medications have been identified as contributing to an increased falls risk. Health professionals need to be cognisant of fall-risk inducing drugs (FRIDs), particularly when in combination with multiple medications, and the potential for non-adherence to medication regimes to contribute to falls when prescribing for older adults. Medication reviews should be included in any standard falls risk assessment. Cessation or modification of problematic medications is a potential intervention (alone or as part of a multifactorial intervention) however, it should be noted that patients may resist medication change, alternative non-FRIDs (where medication is necessary) may not be available, and changes in medication may be difficult to maintain long-term.

The evidence for vitamin D supplements is inconsistent. Vitamin D may reduce falls in older people who are deficient in vitamin D, but not those with normal levels. Combined with calcium supplementation vitamin D may reduce the risk of fracture.

5.2.2 Home Hazards and Environmental factors

Typically, a falls risk assessment will include an assessment of hazards in the home. Checklists are cheap and can be undertaken by anyone, including the older person themselves, regardless of training. However, checklists tend be generic, do not take in to account individual's unique environment and without the involvement of occupational therapists, outcomes are largely unsuccessful. Functional home assessments are considered more comprehensive (although time-consuming and expensive) and are tailored to the individual and how they interact with the home environment. Home modification may be simple e.g., removing hazardous furniture or fittings or more complex where accessibility is an issue, particularly in New Zealand's older homes, where accessibility would not have been incorporated into original design. Home modifications are particularly effective for those with a history of previous falls. There is strong evidence to suggest that where home modifications are identified the involvement of occupational therapists is crucial for implementation of them to be effective. This is even more so for those at high risk of falls.

The benefits of environmental modifications for those with visual impairment is difficult to ascertain, however we did identify one New Zealand study that found a reduction in falls for those with visual impairment who received environment assessment and modification via occupational therapy, again highlighting the importance of OT-lead interventions in this sphere. Those that undertake home assessment and intervention should be aware of the potential for older adults to resist home modifications. They may not see their home as unsafe, may not recognise the benefits of the modifications and prefer their current home configuration. Home assessment should be ongoing to adapt to changes in individuals' functioning.

There is limited research on interventions for outdoor falls protection. There is some support for the use of anti-slip shoe devices in reducing fall rate during icy conditions. The anti-slip devices were reported as being affordable and well-accepted by the participants with a high

compliance rate, so may be very useful for older adults living in areas prone to bad weather. The Stroll Safe program, a seven-week program of educational group sessions focusing on different components of outdoor fall prevention, has also reported success in reducing fall rate and increasing use of fall prevention strategies. While the Stroll Safe program shows potential, this was a feasibility study with a very small sample size and will require further research.

Environmental hazards in the urban built environment also influence falls risk in older adults. While specific interventions for these types of hazards where not identified in the systematic review, a focus on age-friendly communities that promote active ageing may not only address outdoor hazards associated with falls but may also enhance the social environment to mitigate falls risk. Age-friendly environments attempt to maximise social participation, communication, civic participation, community support, respect and social inclusion (Plouffe & Kalache, 2010). Socially cohesive neighbourhoods are associated with a reduction in risk of falls.

There are few interventions targeting footwear but the benefits of wearing the correct footwear for the conditions (e.g., icy conditions) has been reported.

No interventions targeting assistive devices to prevent falls were identified within the review timeframe.

5.2.3 Multifactorial and Multicomponent Interventions

Multifactorial interventions are effective fall-risk interventions as they target multiple different risk factors at the same time, usually determined by assessing the individual and catering the intervention to their specific needs. The literature consistently reports significant reductions in fall risk following multifactorial risk assessment and interventions in healthy or high fall-risk adults but tend to be less effective in frail older adults. They are also more effective when the intervention regime includes active interventions that directly resolve the falls-related risks, as opposed to referral-only regimes which direct the participant to other services.

Multicomponent interventions target multiple risk factors, but the risk factors are not individualised between participants. Most multicomponent interventions include exercise as a core component, and indeed one study reported a greater drop in fall rate in participants who received exercise as part of their intervention when compared with participants who did not receive exercise. Additionally, home modifications were found to be important in multicomponent interventions and led to greater decreases in fall risk.

5.3 Gaps and Limitations in the Literature

This review was limited to the last 10 years of research, although it did include some literature reviews that reviewed studies from before this time period. It also focused on studies that measured fall risk with only a small supplementation of studies that did not, so it may have excluded important interventions for which there is no data explicitly on fall risk yet. During the screening process, this review excluded interventions that focused on people with underlying medical conditions or disabilities. In an aging population this is an important and growing group of people, so it is important to know how interventions may affect people differently, and how they may need to be tailored to be effective in different populations. This review did not address cost efficacy of interventions, which is important to consider when implementing a fall-prevention programme but was outside the scope of the review.

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7 Appendix

7.1 Search strategy

In consultation with a subject librarian, key search terms were identified and used to locate suitable literature within the chosen databases. Primary literature searches were conducted using PsycINFO, Scopus, Web of Science, Medline, CINAHL and PubMed databases. Citation searches to locate grey literature and articles not identified by the search string were conducted using Google Scholar. The search was limited to studies published after 1st January 2010. Resulting citations were downloaded to EndNote.

7.2 Study selection and screening

The titles and abstracts were screened to identify those which were not relevant for inclusion in the review. The type of information in the article (i.e., whether it presents background information, empirical evidence, qualitative evidence, literature review, unclear, irrelevant) were identified. If the document was irrelevant, it was excluded from the full text search. If the document was a literature review, the full text was obtained, and a forward citation search was conducted for additional relevant articles. The reference sections of relevant papers were checked for any further studies that were not identified using the initial search. A citation search was used on each relevant paper to identify more recent studies that have cited the paper. Any relevant studies that were not identified in the initial search were assessed for eligibility. The abstracts were assessed to determine eligibility based on participant age range, research centred around falls as an outcome, focus on risk factors and prevention, and relevance to a New Zealand context. Figure 1 illustrates the flow diagram of the method of summarising selection, screening and inclusion of studies.

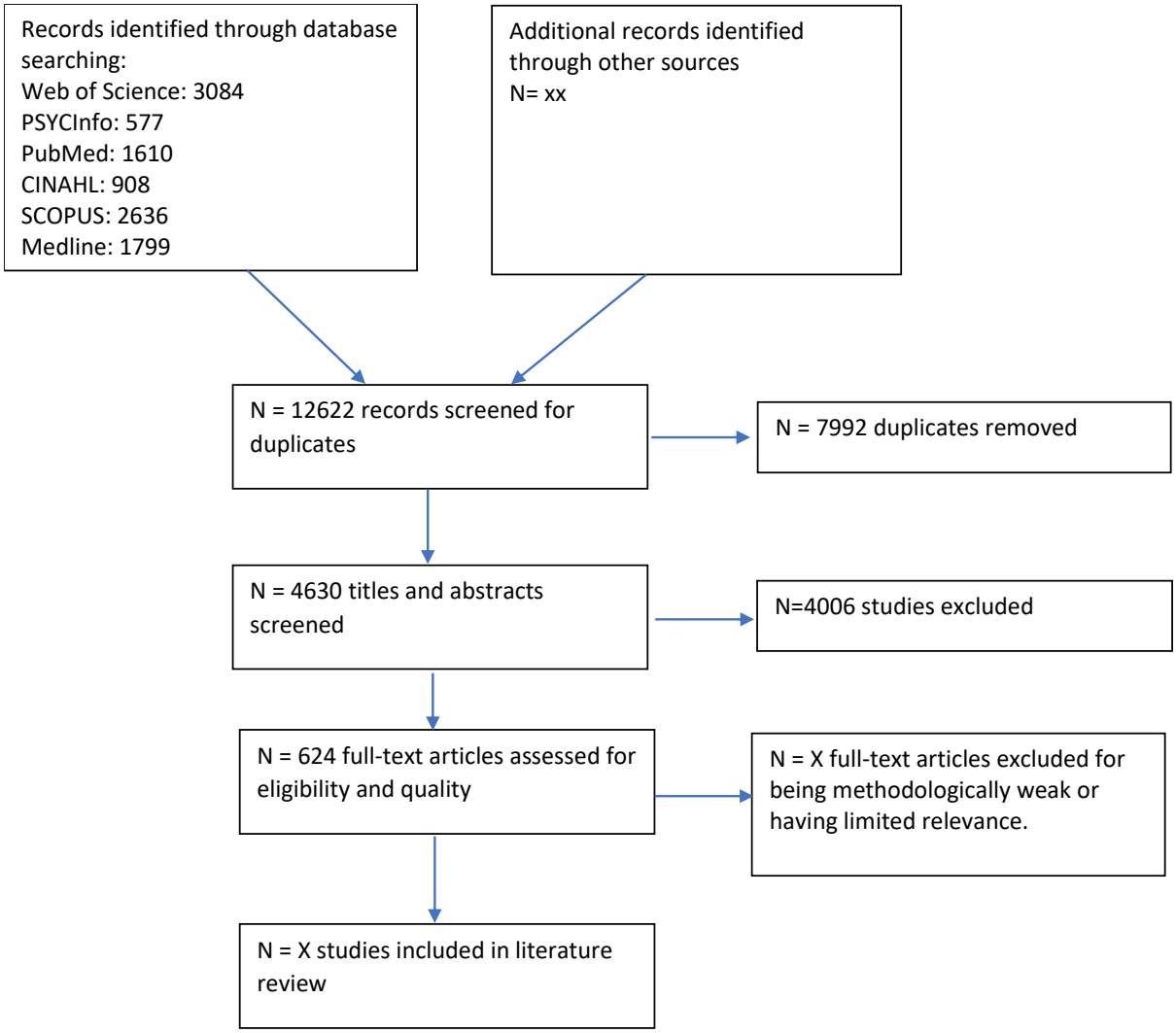

Figure 1. Method of screening process.

The full text of the final records were reviewed, and the quality of the design and conclusions drawn in the final records were assessed for any bias or design problems within the study.

7.3 Data synthesis and analysis

A Microsoft Excel based tool was developed for charting the data from included records. This involved extracting the data from studies based on predetermined criteria and sorting the data into categories for analysis and review. Categories are outlined in Table 1. The evidence extracted from the studies was summarized and compared, and conclusions drawn about potential avenues for further research**.**

Table 1. Categories for data extraction.

Category	Description
Country/Region of Study	New Zealand vs other
Study design	The design used in the study e.g., cross sectional, longitudinal, intervention-control trial, RCT.
Sampling	Did the study used randomised or non-randomised sampling of participants?
Study population/Setting	How was the study population defined?
Data collection	What method/methods were used to collect the data?
Outcome	What was the main outcome or dependent variable being assessed in the study?
Intervention	If the study included an intervention or the assessment of an intervention, then indicate what kind of intervention was used. Note whether it was a culturally-based intervention.
Modifiable risk factors	Note the modifiable risk factors assessed and whether they were significantly associated with falls (univariate and multivariate models)
Demographics	What demographics were collected? (e.g., age group, gender, ethnicity, education)

7.4 Intervention studies reviewed

Study	Intervention category	Participants	Type of study	Intervention method	Measures	Findings	Location
Kittipimpanon et al. (2012)	Community-based, multifactorial	N = 41, mean age 72.9 years	Action research	Community-based fall prevention program including multifactorial risk assessment, fall prevention campaign, education program, balance/ exercise activity, home visits and a fall management system.	Fall incidence rate, fall prevention behaviours, physical performance, environmental hazards, satisfaction with the program.	Falls were reduced by 24.86%, significant improvement in overall fall prevention behaviours, significant improvement in lower body strength, balance and gait.	Bangkok, Thailand
Kramer et al. (2014)	Community-based, multifactorial	N = 200, mean age	Quasi-experimental, within-subjects, pretest-posttest.	InSTEP: 12-week program including physical activity, medical risk, home safety. Three different levels of intensity.	Fall incidence, physical performance, home safety assessment.	Overall, participants reported less falls at each time point after the intervention. Medium level intensity model significantly reduced self-reported falls compared with other models.	USA
Otaka et al. (2017)	Community-based, multifactorial	N = 603, mean age 73.1 years	Prospective controlled trial	Either a single visit from a multidisciplinary team including education and fall risk assessment or a year-round comprehensive program with visits every three months.	Fall rate, comprehensive fall risk assessment, fear of falling.	Fall rates for both programs decreased significantly by 43% over the trial period. No significant difference in fall rate between groups.	Japan
Merom et al. (2016)	Dancing	N = 530, mean age 78 years, nursing home residents.	RCT	Group social dancing: twice weekly one-hour classes over 12 months. Control: continued with regular activities.	Falls, physiological and physical performance.	No significant difference in fall incidence between groups. Ballroom dancing improved gait speed significantly compared with control.	Australia
Alison C. Pighills, David J. Torgerson, Trevor A. Sheldon, Avril E. Drummond, and J. Martin Bland (2011)	Environmental assessment and modifications	N = 238, aged 70+	Pilot three-armed RCT	Assessment and modification of the home environment carried out by either occupational therapists (OTs) or trained assessors (Tas)	Fear of falling, falls, quality of life, independence in activities of daily life.	No effect on fear of falling, significantly fewer falls in the OT group compared with controls, no effect on falls in the TA group.	England
Albert and King (2017)	Exercise	N = 560, mean age 75.3 years.	Prospective cohort	Healthy Steps in Motion (HSIM) programme offered through senior centres, compared with education-based programme without exercise.	Self-reported fall incidence over 6 months	When comparing the two programmes, there was a non-significant 18% reduction in falls in the HSIM programme. Among participants who did not experience a fall in the previous 12 months, there was a significant reduction in falls in the HSIM group.	USA
Binns and Taylor (2011)	Exercise	N = 37, aged 80+	Clinical trial	Otago Exercise programme:	Lower limb strength, balance, mobility, falls self-efficacy.	Falls were not measured. No significant difference in measures of strength and balance compared with control group.	New Zealand
Greenwood-Hickman et al. (2015)	Exercise	N = 70,798, aged 65+	Retrospective cohort	Examined effect on falls of two widely available exercise programs for older adults (EnhanceFitness and Silver Sneakers). Participants classified as consistent users (used program more than once in all years) or intermittent users (used program more than once in 1 or more years).	Time to first fall requiring hospital medical treatment.	Consistent and intermittent EnhanceFitness users had a reduced risk of falls resulting in medical care. Intermittent Silver Sneakers users also had reduced fall risk.	USA
Sivan, Sawyer, and Brown (2010)	Exercise	N = 8 RCTs	Literature review	Literature review of RCTs testing effect of exercise intervention on falls.	N/A	Falls or number of fallers were significantly reduced compared with control groups in all but one of the trials.	-
Day et al. (2015)	Exercise - Tai chi	N = 503, aged 70+, preclinically disabled	Multisite parallel group individually RCT	60-minute Sun style tai-chi, twice per week in a group setting for 48 weeks. The control group participated in a group flexibility session twice per week for the same period.	Self-reported falls using monthly calendar, injurious falls.	No change in falls, but more participants failed to complete the programme in the intervention group.	Australia
Saravanakumar et al. (2014)	Exercise – Tai chi and yoga	N = 33 aged care facility residents, mean age 83.8.	RCT	Either yoga or tai chi: 14-week programme, twice per week, half hour sessions. Compared with usual care control group.	Balance, fall incidence, pain and perceived quality of life.	No significant difference in outcomes between three groups, but may be due to low power of feasibility study.	Australia
Li et al. (2018)	Exercise – Tai Ji Quan	N = 670, mean age 77.7 years, with history of falls or impaired mobility.	RCT	Tai Ji Quan compared with multimodal exercise intervention or stretching as control.	Fall incidence at 6 months.	Tai Ji Quan intervention reduced falls by 58%, compared with stretching, and reduced falls by 31% compared with the exercise intervention.	USA

Study	Intervention category	Participants	Type of study	Intervention method	Measures	Findings	Location
Lurie et al. (2013)	Exercise – Treadmill training	N = 73, aged 64+	Randomized pilot study	Standard PT (control) compared with surface perturbation treadmill training. Training protocol included trip simulations.	Falls assessed via phone call after 3 months, feasibility, injurious falls, medical records, fall risk.	No significant difference in risk of falls, likely due to low power of study.	USA
L. Dillon et al. (2017)	Exercise and home modifications	N = 19, aged 63+, visually impaired	Qualitative	Focus group and semi-structured interviews	N/A	Participants did not see themselves as needing fall intervention and did not attribute falls to their vision. This population had unique barriers to fall prevention that need a tailored approach.	Australia
M. Di Monaco et al. (2012)	Home and behaviour recommendations	N = 95 women with fall-related hip fracture	Post-hoc analysis of quasi-RCT.	Assessed home fall hazard and suggested targeted modifications of environment and behaviours.	Falls recorded at six-month follow-up home visit.	Women with greater than 2 uncorrected risk factors had significantly higher risk of falling than those with less than two risk factors. Greater adherence to recommendations was associated with lower fall risk.	Italy
Tomoko et al. (2015)	Home hazard education / modifications	N = 130, mean age 75.7 years	RCT	Both groups received a multifactorial program including education, food and nutrition, foot care, and exercise. The intervention group also education and practice in home safety using model homes.	Falls, fall location, fall prevention awareness, home modifications.	Falls significantly reduced in participants over age 75 in both groups. Intervention group had more fall prevention awareness at 52 week follow up and a greater number of home modifications.	Japan
Campani et al. (2020)	Home modification	N = 2 articles	Review	Home modifications	N/A	Home modification is effective in reducing falls in people aged 65+. Important modifications include slip-resistant flooring, lighting, furniture and layout changes. Home assessment and modification is low-cost and highly cost-effective.	Italy
Carlsson, Nilsson, Ekstam, Chiatti, and Fange (2017)	Home modification	N = 196, mean age 80 years	Quasi-experimental with non-equivalent control.	Occupational therapist-led standardized home assessment and adaptation.	Fear of falling and falls before, 3 months and 6 months after intervention.	Significant improvements in fear of falling at the 3-month assessment, but not at 6 months. No change in falls.	Sweden
Crowell and Sokas (2020)	Home modification	N = 51, 82.7% over age 70	Quasi-experimental	Follow up phone call following participation in the Safe at Home program (home assessment and modification).	Satisfaction with the program, number and nature of falls, falls efficacy scale.	Intervention was well-received, FES scores significantly reduced indicating less fear of falling, number of falls were significantly reduced.	USA
Guerra et al. (2021)	Home modification	N = 118 with arterial hypertension, aged 65+	RCT	Participants received nursing-based guidelines for modifying environmental and behaviour fall risk factors.	Self-reported falls.	Intervention group experienced significantly less falls than control group.	Brazil
Kruse et al. (2010)	Home modification	N = 10, age 60-90 years	Qualitative	Home assessment and modifications followed by semi-structured interviews.	Perceptions of home modification	Participants did not see falls as a problem, did not like being told to change their home, did not believe modifications would have an effect and did not think they required assistance. Fall prevention strategies are linked to the home-self relationship and this must be taken into account when modifying homes.	USA
J. Pynoos et al. (2010)	Home modification	N/A	Literature review	Home assessment and modifications	Fall risk	Important to consider home assessment and modification alongside health and functioning, as well as behaviour pattern. Occupational therapists are well-situated to provide this type of intervention.	N/A
Jon Pynoos, Steinman, Do Nguyen, and Bressette (2012)	Home modification	N/A	Literature review	Home assessment and environment modification.	N/A	Home assessments should include interactions between the environment and the behaviour and physical functioning.	USA
Stark, Keglovits, Arbesman, and Lieberman (2017b)	Home modification	N = 36 articles	Systematic review	Home modification	N/A	Home modification interventions are effective in in improving function, both in single intervention and as part of multifactorial interventions. Occupational therapy also has an important role.	USA

Study	Intervention category	Participants	Type of study	Intervention method	Measures	Findings	Location
Condurache et al. (2020)	Medical factors	N = 12,483, aged 70-85 years, all women	Post-hoc analysis	SCOOP study: participants randomised to either control or screening; screened participants were recommended osteoporosis treatment if they were found to be at risk of hip fracture.	Self-reported falls, FRAX 10-year probability of hip fracture	Higher FRAX 10-year probability of hip fracture was associated with higher risk of falls. No difference in falls between control and screening groups.	England
Mott et al. (2016)	Medication (FRID) review	N = 80, aged 65+	RCT	Medication therapy management: 60-minute face to face medication review and follow-up with intention to modify identified FRID use.	FRID use by 6-month follow up, falls (monthly self-report), medication-related problems.	No significant change in self-reported falls.	USA
Najafi-Ghezeljeh et al. (2019)	Multicomponent fall prevention intervention	N = 160, mean age 67.6 years, nursing home residents.	Pretest-posttest quasiexperimental	Multicomponent fall prevention intervention.	Fall frequency, mobility balance, depression.	The multicomponent intervention reduced fall frequency and depression and improved mobility and balance.	Iran
T.-Y. Chen (2014)	Multicomponent: A Matter of Balance (MOB)	N = 103, mean age 75	Prospective cohort	MOB program: multifaceted cognitive-behavioural intervention, aims to improve falls self-efficacy through education, goal setting, environment modification and physical exercise.	Falls, mobility, pain, functional limitations, chronic conditions, cognitive function, fear of falling.	Total reported falls did not differ between the control and intervention group from pre- to post-test. Participants in the MOB group had significantly better mobility, walking speed and postural control at post-test.	USA
Formosa et al. (2014)	Multidisciplinary	N = 51, mean age 77.5	Prospective cohort	Multidisciplinary falls risk assessment followed by recommendations based on the outcome of the assessment. Follow up 6 months later.	Need for medical attention, falls, injuries	Significant reduction in reported falls, injuries and required medical attention following the multifactorial intervention. Severity of injuries was less; less reported fractures.	Australia
Hopewell et al. (2018)	Multifactorial	N = 62 trials	Cochrane review	Literature review of multifactorial and multicomponent fall prevention intervention trials in community-dwelling older adults.	N/A	Multifactorial interventions may reduce rate of falls, but little effect on other fall-related outcomes. Multiple component interventions including exercise may reduce rate and risk of falls.	-
Y. A. Johnston et al. (2019)	Multifactorial	N = 10,479, aged 65+	Cohort study	STEADI: Screening for falls risk, assessment of modifiable risk factors (medication, functional ability, vision, blood pressure, podiatry review, home hazards), targeted interventions to reduce fall-risk.	Fall risk, fall rate before and after intervention, hospitalizations.	The STEADI initiative was associated with reduced fall-related hospitalizations for older adults at risk of falls.	USA
Tripken, Elrod, and Bills (2017)	Multifactorial	N = 23, mean age 74.3 years	Pilot study: pretest-posttest	Interdisciplinary falls prevention program consisting of 90-minute sessions, once per week for 5 weeks at a community centre. Sessions addressed risk factors for falls (awareness, physical activity, medication, home safety). Individual action plans were created for participants.	Demographics, falls efficacy, Fall Prevention Survey, personal self-efficacy.	Positive improvements measured across all outcomes.	USA
S. H. Lee and Yu (2020a)	Multifactorial	N = 45 articles	Systematic literature review	Multifactorial fall prevention interventions	Components of multifactorial intervention, active vs referral, number of falls.	Active multifactorial interventions were effective in reducing falls, interventions that included exercise and environmental modification were more effective.	Korea
H.-C. Lee et al. (2013a)	Multifactorial	N = 616, mean age 75.5 years, community-dwelling	RCT	Multifactorial fall prevention with exercise program compared with control group.	Fall incidence within 1 year, PPA battery, TUG test, physical activity, depression, falls efficacy at 3 months.	No difference between groups in fall incidence at 1-year follow up, but intervention group had improved functional performance at 3 months.	Taiwan
Matchar et al. (2017)	Multifactorial	N = 354, aged 65+, fall history	RCT	SAFE: Mutlifactorial program involving physical therapy, screening for vision, medication use, and environmental hazards. Control group received usual care and educational materials on fall prevention.	Experiencing at least 1 fall during 9-month study period, injurious fall, Short Physical Performance Battery scores. Assessed at 3 and 9 months.	No significant difference between groups. People with less than 2 comorbidities had reduced falls, whereas people with 2 or more comorbidities had no change in falls.	Singapore
Russell et al. (2010)	Multifactorial	N = 712, aged 60+	RCT	Targeted multifactorial falls prevention program (referral-based) compared with usual care.	Falls and injuries within 12 months follow-up period.	Intervention was not effective in preventing further falls and related injury.	Melbourne, Australia

Study	Intervention category	Participants	Type of study	Intervention method	Measures	Findings	Location
Stam et al. (2018)	Multifactorial	N = 168, mean age 78.8 years, experienced dizziness	RCT	Multifactorial intervention including medication adjustment, mental health care, exercise therapy. Compared with usual care.	Dizziness-related impairment, QoL, dizziness frequency, fall frequency, anxiety, depression, use of FRIDs.	The intervention significantly reduced the use of FRIDs. No significant effect on dizziness-related impairment, fall frequency or any other measures.	The Netherlands
Chase et al. (2012)	Multifactorial / Home modifications / exercise	N = 33 articles	Systematic review	Home modifications	N/A	The most effective programs were multifactorial ones including home modifications, exercise, education, and vision and medication review. Some evidence for exercise and home modifications as single interventions.	USA
Karinkanta et al. (2010)	Physical therapy	N/A	Review	Review on various physical therapy approaches to reduce fall risk.	N/A	Exercise, home hazard assessment and modification, hip protectors, anti-slip shoe devices and vibration training show potential for reducing fall risk. Multifactorial interventions must be tailored to high-risk populations.	-
Rosenblatt et al. (2020)	Podiatry	N = 41 articles	Literature review	Shoe modifications, foot and ankle exercises, general foot and podiatric care, surgical interventions.	N/A	Multifactorial interventions including foot assessment, foot care, insoles and exercises were effective in reducing falls.	USA
Hansma et al. (2010)	Standardised individual falls-assessment	N = 53, mean age 79.8 years	Retrospective cohort	Standardized falls assessment, followed up by phone.	Number of interventions, number of falls, number of risk factors.	Falls assessment significantly reduced the number of falls per year and fear of falling. Assessment allowed for identification of risk factors that can be addressed.	The Netherlands
Wilmink et al. (2020)	Technology	N = 490, living in assisted living communities.	Retrospective cohort	AI-powered digital health platform involving wearable sensors.	Hospitalization rate, fall rate.	Residents of assisted living communities that utilized the health platform had lower hospitalization rate and lower fall rate. Health platform helped staff identify at-risk adults and can be used to intervene earlier and prevent health decline.	USA
L. D. Gillespie et al. (2012)	Various - review	N = 111 trials	Systematic review	Multiple	N/A	Tai chi, home exercise and multi-component group exercise reduced fall rate and risk of falls. Multifactorial interventions did not reduce fall risk, but did reduce rate of falls. Vitamin D may reduce falls in people with low Vitamin D levels, but not normal levels. Medication withdrawal reduced rate of falls but not fall risk. Home safety interventions reduced falls in people with visual impairment or at high risk of falls, but not overall.	UK
Rossi-Izquierdo et al. (2020)	Vestibular rehabilitation (VR)	N = 57	RCT	Computerized dynamic posturography training or optokinetic stimulus compared with control (exercise at home).	Stability, modified timed up and go, number of falls, dizziness, falls efficacy.	VR is effective in reducing falls in patients with reduced stability.	Spain
Buckinx et al. (2014)Buckinx et al. (2014)	Vibration training	N = 62, mean age 83.2 years, nursing home residents	RCT	Vibration training: 6-month exercise program, 3x per week. Control: no change in activities.	Balance and gait, mobility (TUG), walking analysis, falls reported by nurses.	No effect on falls, walking analysis, mobility, balance and gait between groups.	Belgium
Parsons et al. (2016)	Vibration training	N = 56, mean age 82 years, inpatient rehabilitation unit in regional hospital.	RCT	Vibration training: 3x per week until discharged.	Physiological profile assessment (PPA), functional independence measure (FIM), falls efficacy.	Significant improvement in FIM and falls efficacy, but no difference in PPA.	NZ
Mirelman et al. (2016)	Virtual reality augmented treadmill training	N = 661, mean age 73.3 years, community-dwelling.	RCT	Six weeks treadmill training plus VR compared with treadmill training without VR.	Incident rate of falls in 6 months after training, gait, foot clearance, attention and executive function, endurance, balance, mobility, health-related QoL.	Both treadmill training groups had reduced fall rates after training, and other measures were significantly improved. Treadmill training + VR was significantly more effective in reducing falls in the 6 months after training and improving fall risk.	Belgium, Israel, Italy, the Netherlands, UK

Study	Intervention category	Participants	Type of study	Intervention method	Measures	Findings	Location
Sanders et al. (2010)	Vitamin D	N = 2,256 women, aged 70+	Double blind, placebo-controlled trial.	Annual oral dose of 500,000 IU cholecalciferol in autumn or winter for 3-5 years. Compared with placebo.	Falls and fractures.	Annual high-dose cholecalciferol was associated with increased risk of falls and fractures.	Australia
K. Uusi-Rasi et al. (2015)	Vitamin D supplement and exercise	N = 409 women, 70-80 years old	RCT	Four groups: 1) placebo with exercise, 2) placebo without exercise, 3) vitamin D (800 IU/d) with exercise, and 4) Vitamin D (800IU/d) without exercise.	Monthly reported falls, injurious falls, number of fallers, bone density, physical functioning, vitamin D metabolism.	Neither vitamin D nor exercise reduced falls. The rate of injurious falls was significantly reduced in the exercise groups, regardless of vitamin D treatment. Vitamin D helped maintain bone density.	Finland
Kwok and Pua (2016)	Wii	N = 80, mean age 70 years, mild to moderate frailty,	Parallel assessor-blinded block-randomised active-controlled trial	Wii: once weekly 1 hour supervised intervention including 20 minutes of Wii Active gaming exercises. Gym: once weekly 1 hour supervised gym exercise class. 12-week intervention trial, follow-up at weeks 13 and 24.	Fear of falling (primary), knee extensor strength (KES), one-year fall incidence (self-report via monthly calendar), gait and balance, intervention satisfaction.	No significant reduction in falls. Significant improvements in fear of falling in both groups, but only maintained at the 24-week follow up in Wii group. Both groups improved in KES, gait and balance.	Singapore