COMPLIANT FLOORING FOR FALL INJURY PREVENTION IN LONG-TERM CARE

by

Chantelle C. Lachance

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Approval

Name: **Chantelle C. Lachance**

Degree: **Doctor of Philosophy**

Title: ***Compliant Flooring for Fall Injury Prevention in Long-term Care***

Examining Committee: **Chair:** Thomas Claydon, PhD
Associate Professor

Dawn C. Mackey, PhD
Senior Supervisor
Assistant Professor

Stephen N. Robinovitch, PhD
Supervisor
Professor

Fabio Feldman, PhD
Supervisor
Adjunct Professor

Scott Lear, PhD
Internal Examiner
Professor
Biomedical Physiology and Kinesiology

Lora Giangregorio, PhD
External Examiner
Associate Professor
Kinesiology
University of Waterloo

Date Defended/Approved: March 6, 2017

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

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Abstract

A promising strategy for reducing the incidence and severity of fall-related injuries in long-term care (LTC) is to decrease the ground surface stiffness, and the subsequent forces applied to the body parts at impact, through installation of compliant flooring. Evidence about the feasibility of compliant flooring in LTC is extremely limited. My PhD research addresses this gap by conducting a comprehensive, multimethod evaluation of compliant flooring. Specifically, I investigate the feasibility of compliant flooring for fall injury prevention in LTC by synthesizing the available evidence (study 1), determining the effects of compliant flooring on external hand forces exerted by LTC staff when pushing wheeled equipment (study 2), and examining the barriers to and facilitators of implementing compliant flooring as perceived by key stakeholders (studies 3 and 4). In my first study, I conducted a scoping review to describe the extent, range, and nature of research activity on compliant flooring, and to identify research gaps and directions for future research. I found compliant flooring is a promising strategy for preventing fall-related injuries from a biomechanical perspective. Additional research is required, however, to determine whether compliant flooring prevents fall-related injuries in real-world settings, is a cost-effective intervention strategy, and can be installed without negatively affecting workplace safety. My second study compared the effects of flooring system and resident weight on the forces required by LTC staff to push floor-based lifts used to transfer residents. Compared to the conventional lift, the motor-driven lift substantially reduced forces in all experimental conditions and thus may help to address risk of work-related musculoskeletal injury. My third study examined the feasibility of compliant flooring from the perspective of organizational-level LTC stakeholders. My interview findings provide new evidence about facilitators and barriers that stakeholders consider in deciding to install compliant flooring in LTC, such as staff's openness (or resistance) to change and flooring performance. My fourth study sought input about compliant flooring from additional stakeholders through a symposium. My findings suggest that while stakeholders perceive compliant flooring to add value to the LTC setting, there also remain significant informational and financial barriers to the uptake of compliant flooring. Overall, my thesis should inform planners and architects in the development of safer environments for vulnerable older adults, and improve policies and programs for fall injury prevention in LTC.

Keywords: compliant flooring; long-term care; injury prevention; falls; older adults; multimethod

Dedication

To my late grandfather, Lloyd Fox, and late grandmother, Mariette Lachance.

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List of Acronyms

95% CI	95% confidence interval
ANOVA	analysis of variance
CAD	Canadian Dollar
CBR	cost-benefit ratio
CEO	Chief Executive Officer
CI	confidence interval
F_{init_dwn}	initial downward force
F_{init_fwd}	initial forward force
F_{init_res}	initial resultant force
FLIP	Flooring for Injury Prevention
F_{sust_dwn}	average downward force
F_{sust_fwd}	average forward force
F_{sust_res}	average resultant force
GBP	British Pound
KTA	knowledge-to-action
HR	heart rate
IR	incidence rate
IRR	incidence rate ratio
LTC	long-term care
MSI	musculoskeletal injury
NCF	novel compliant flooring
NZD	New Zealand Dollar
OBD	occupied bed days
RaR	rate ratio
RR	relative risk
SD	standard deviation
SE	standard error
SEK	Swedish Krona
TBI	traumatic brain injury
T_{init}	instant of peak forward force
T_{min}	2 seconds before the instant of minimum forward force
T_{sust}	sustained phase of forward force
USD	United States Dollar

Published Studies

Chapter 1	Sections of this chapter have been published as a protocol, under modified format, as: Lachance CC, Feldman F, Laing AC, Leung PM, Robinovitch SN, Mackey DC. Study protocol for the Flooring for Injury Prevention (FLIP) Study: a randomised controlled trial in long-term care. Injury prevention. 2016 Dec 1;22(6):453-60.
Chapter 2	Sections of this chapter have been published as a protocol, under modified format, as: Lachance CC, Jurkowski MP, Dymarz AC, and Mackey DC. Compliant Flooring to Prevent Fall-Related Injuries: A Scoping Review Protocol. BMJ open. 2016 Aug 1;6(8):e011757. The results of this chapter have been published as Lachance CC, Jurkowski MP, Dymarz AC, Robinovitch SN, Feldman F, Laing AC and Mackey DC. Compliant Flooring to Prevent Fall-Related Injuries in Older Adults: A Scoping Review of Biomechanical Efficacy, Clinical Effectiveness, Cost-Effectiveness, and Workplace Safety. PLoS ONE. 2017 Feb 6; 12(2): e0171652.
Chapter 3	Lachance CC, Korall AM, Russell CM, Feldman F, Robinovitch SN, Mackey DC. External Hand Forces Exerted by Long-Term Care Staff to Push Floor-Based Lifts Effects of Flooring System and Resident Weight. Human Factors. 2016 Sep;58(6):927-43.
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Chapter 1. Introduction

In this thesis, I will investigate the role of compliant flooring, in particular its feasibility, as an intervention to prevent fall-related injuries among older adults in long-term care (LTC). In the first section of the introduction, I provide a broad overview of the prevalence and consequences of falls and fall-related injuries among older adults. This epidemiological evidence highlights the magnitude of this public health problem and suggests LTC residents are among the most vulnerable populations at risk for falls and fall-related injuries. Second, I describe the current available evidence on preventing falls in older adults and highlight the significant challenges of preventing falls specifically in the LTC environment. This leads to the notion that efforts to prevent fall-related injuries may be more effective than efforts to prevent falls in the LTC setting. Third, I describe the currently available strategies to prevent fall-related injuries in LTC and provide evidence of the demand for new approaches. Fourth, I propose compliant flooring as a novel strategy to prevent fall-related injuries for LTC residents. I describe the current literature about compliant flooring and present gaps in the available evidence. Finally, I present a conceptual framework that links the specific aims of my thesis.

1.1. Epidemiology of falls and fall-related injuries in older adults

Falls and the injuries they cause are a major public health concern for older adults, and a substantial burden to our health care system. Falls were the leading cause of overall injury costs in Canada, accounting for $8.7 billion of the $26.8 billion (34%) in 2010 [1]. Of that amount, older adults' (65+ years) falls accounted for $3.4 billion dollars. **Table 1.1** provides a breakdown of the total direct and per capita costs by age and sex and reflects the importance of prevention efforts [1].

Table 1.1. Total direct and per capita costs of injury due to falls by age and sex, Canada, 2010

	Reference Population	Total Cost ($ Millions)	Per Capita Cost ($)
Women			
65-74	1345726	511	379.51
75-84	906514	814	898.26
85+	421113	902	2142.29
Total Women	2673353	2227	833.04
Men			
65-74	1233815	369	298.85
75-84	691899	454	656.03
85+	197076	318	1615.82
Total Men	2122790	1141	537.50
Grand Total	4796143	3368	702.23

Source: Table adapted from Parachute (2015). The cost of injury in Canada. Parachute: Toronto, ON [1].

1.1.1. Falls in older adults

The rates of falls among older adults vary substantially by setting. Approximately 30% of community-dwelling older adults fall each year [2] and 50% of those individuals will suffer multiple falls each year [3]. In acute care, between 3% and 20% of older adults fall at least once during their hospital stay, with published fall rates ranging from three to 20 per 1000 bed days [4–8]. In fact, in-hospital falls are the most common among incidents in acute care, with approximately 40% of all reported acute care adverse events. Falls in acute care may be secondary to changes in health status (e.g., recovering from an acute illness), medication use (e.g., new medications, polypharmacy, benzodiazepines), or environment (e.g., room/unit change) [9,10]. Older patients with chronic gait instability or cognitive impairment are more likely to fall in acute care [9,10]. Furthermore, falls in acute care are associated with increased length of stay and higher rates of discharge to LTC [10].

The LTC setting is a particularly high-risk environment for falls, as LTC residents often present with lower physical and cognitive status than older adults living independently in the community [11]. LTC in Canada refers to sites for older adults where personal and nursing care is provided on a 24-hour basis [12] for individuals who have complex care needs and can no longer be cared for in their own homes or in an assisted living residence [13]. In Canada, 4.5% of older adults live in LTC [14]. Approximately 60% of LTC residents fall at least once per year, rates that are 2-3 times higher than for community-dwelling older adults [11,15–19].

1.1.2. Fall-related injuries in older adults

No matter the setting, any fall can have repercussions on the older adult. Indeed, falls are the leading cause of injury-related death, hospitalizations, and unintentional injury among older Canadians [3,20–22]. In Canada, the number of deaths due to falls increased by 65% between 2003 (1631 deaths; age-standardized mortality rate: 3.5 per 10 000) and 2008 (2691 deaths; 4.7 per 10 000) [23]. Falls account for 85% of all injuries that result in hospitalization among older adults, and older adults who are admitted to hospital for a fall-related injury are hospitalized for an average of nine days longer than those hospitalized for any other cause [21,23]. Fall-related injuries can have lasting and devastating consequences, including increased mortality and decreased independence and quality of life [24]. Even falls that do not result in physical injury can lead to negative psychological and physical health outcomes, including fear of falling, functional decline, immobilization, loss of autonomy, social isolation, confusion, and depression [23,25,26].

Aside from death, hip fractures and traumatic brain injuries are the most serious injuries an older adult can sustain from a fall. Falls cause up to 95% of hip fractures [22,23], and there are approximately 30,000 hip fractures annually in Canada [27,28]. Approximately 25% of hip fracture patients die within one year of the fracture [29], and 50% do not return to their pre-fracture level of mobility, quality of life, or independence [30–32]. Falls also cause 80% of traumatic brain injuries [33–35], 90% of wrist fractures [36,37] and a large proportion of shoulder, elbow, lower back, and spine injuries in older adults [23]. Traumatic brain injuries have tripled in incidence over the past decade [34,38,39], and they now cause over half of all fall-related deaths in older adults [40]. Non-fatal traumatic brain injuries may result in long-term cognitive, emotional, and functional impairments [41].

In addition to having an increased rate of falls, older adults living in LTC seem to be more susceptible to injury in the event of a fall. While about 10-15% of falls among community-dwelling older adults result in serious injuries [42], approximately 30% of falls in acute and LTC cause injury [11,15–19,43,44]. Moreover, LTC residents are ten times more susceptible to sustaining a hip fracture [16,17,45] and experience higher mortality rates post-fracture than community-dwelling older adults [46–49]. Furthermore, approximately 25% of fall-related traumatic brain injuries in older adults occur in LTC [34].

1.2. The challenge of preventing falls in LTC

Falls in older adults are often precipitated by several factors, including intrinsic (or biological), behavioural, extrinsic, and situational factors **(Table 1.2)** [23,50]. In general, falls in older adults are not typically the result of a single factor occurring in isolation, but are complex events caused by a combination of these factors [50]. This partially explains why LTC residents are the most vulnerable to fall and fall-related injuries: they have more risk factors associated with these outcomes compared to older adults residing in other settings. For example, increased age, male sex, higher care classifications, incontinence, psychoactive medication use, previous falls and slow reaction times were associated with an increase in falls in LTC [51,52].

Table 1.2 Risk factors associated with falls

Type of Risk Factor	Examples
Intrinsic (Biological)	• Age-related physiological changes (e.g., reduced muscle mass; decreased speed of walking, step length and toe clearance; greater sensitivity to glare and decline in depth perception) • Presence of (acute and/or chronic) disease
Behavioural	• History of previous falls • Lack of maintenance, malfunction, improper fit or overreliance of assisted devices • Risk taking • Medication use, especially psychotropic, sedative, hypnotic drugs • Improper footwear (e.g., wrong size, soles too thick, tread to smooth, heel too high)
Extrinsic	• Physical environment (e.g., clutter, low toilet seats, lack of grab bar support, tripping over non-secure floorcoverings, slipping on wet ground surfaces) • Relocation [e.g., moving from home to acute care (or vice versa), home to LTC, or from one resident room/ward to another]
Situational	• Presence or absence of care providers (e.g., nocturnal falls are attributed to older adults getting up to toilet on their own and the lower staffing levels during these times in institutionalized setting)

Sources: Public Health Agency of Canada. Seniors' falls in Canada: second report. [Internet]. Ottawa, ON; 2014. Available: http://www.phac-aspc.gc.ca/seniors-aines/publications/public/injury-blessure/seniors_falls-chutes_aines/assets/ pdf/seniors_falls-chutes_aines-eng.pdf [23]; Tideiksaar R. Falls in older people: Prevention and management. 4th ed. Health Professions Pres; 2010 [50].

1.2.1. Interventions for preventing falls in older adults living in the community

A recent Cochrane systematic review focusing on older adults living in the community suggested that exercise programs and home safety interventions reduce the *rate* and *risk* of falling [2]. Specifically, multi-component group exercise programs, usually containing balance and strength training exercises, reduced the rate of falling by 29% [Rate Ratio (RaR) 0.71, 95% confidence interval (CI) 0.63 to 0.82; 16 trials; 3622 participants] and risk of falling by 15% [Relative Risk (RR) 0.85, 95% CI 0.76 to 0.96; 22 trials; 5333 participants]. Similarly, multi-component home-based exercise also reduced the rate and risk of falling by 32% (RaR 0.68, 95% CI 0.58 to 0.80; 7 trials; 951 participants) and 22% (RR 0.78, 95% CI 0.64 to 0.94; 6 trials; 714 participants), respectively. Interventions to improve home safety (e.g., installation of grab bars, removing clutter) were effective at reducing the rate and risk of falls, especially with older adults who were at a high risk of falling and the intervention was carried out by an occupational therapist (RaR 0.69, 95% CI 0.55 to 0.86; 1443 participants, 4 trials; RR 0.79, 95% CI 0.70 to 0.91; 1153 participants, 5 trials) [2].

Multifactorial assessments and some single component intervention programs were able to reduce the *rate* of falls in community-dwelling older adults (i.e., number of falls over a defined time period), but not the *risk* of falling (i.e., number of fallers) [2]. For example, multifactorial assessments that included an individual fall risk assessment reduced the overall number of falls by 24% (RaR 0.76, 95% CI 0.67 to 0.86; 19 trials; 9503 participants), but not the number of older adults falling during follow-up. The first cataract eye surgery reduces a woman's rate of falls by 34% (RaR 0.66, 95% CI 0.45 to 0.95; 1 trial; 306 participants). However, this decrease in fall rate was not significant for men or for women having cataract surgery for their second eye. In addition, the insertion of a pacemaker reduces rate of falls by 27% (RaR 0.73, 95% CI 0.57 to 0.93; 3 trials; 349 participants) for older adults who are frequent fallers associated with carotid sinus hypersensitivity. For community-dwelling older adults who experience debilitating foot pain, regular podiatry assessments and foot and ankle exercises reduced the number of falls by 36% (RaR 0.64, 95% CI 0.45 to 0.91) [2].

Finally, Tai Chi reduced the *risk* of falling by 29% (RaR 0.72, 95% CI 0.52 to 1.00; 5 trials; 1563 participants) for community-dwelling older adults, but bordered significant for *rate* of falling (RaR 0.72, 95% CI 0.52 to 1.00; 5 trials; 1563 participants) [2]. The review reported that vitamin

D did not reduce the risk or rate of falling, but may be effective for older adults living in the community who have low vitamin D levels before treatment [2].

1.2.2. Interventions for preventing falls in older adults in institutionalized settings

Despite substantial efforts, preventing falls among older adults in acute care and LTC remains a significant challenge [51,53,54]. With advances in science and medicine, we have seen new fall prevention strategies evaluated in practice, and we have seen traditional fall prevention strategies that are no longer widely implemented. For example, the use of physical restraints was previously common practice in acute and LTC with the reported prevalence of restraint use ranging from 33-68% in acute care and 41-64% in LTC between 1999-2004 [55]. Many adverse events due to restraint use have been reported in the scientific literature, including pressure sores, depression, aggression, and death [55]. With the growing evidence that physical restraints are not adequate intervention for the prevention of falls, many health care sites now follow a least restraint policy to conform with the evidence and the social movement of residents having the “right to live at risk” [55,56].

A recent Cochrane systematic review focused on older adults living in acute care and LTC revealed that the most supported interventions for preventing falls in acute care were supervised exercise and multifactorial interventions [51]. Supervised exercise appeared to be an effective intervention to reduce the risk of falling in subacute hospitals, such as rehabilitation wards (RR 0.44, 95% CI 0.20 to 0.97; 3 trials, 131 participants). In addition, multifactorial interventions reduced the rate of falls (RaR 0.69, 95% CI 0.49 to 0.96; 4 trials, 6478 participants) and the risk of falling (RR 0.73, 95% CI 0.56 to 0.96; 3 trials, 4824 participants) when pooling the data from both acute and subacute care settings. Multifactorial inventions included more than one type of intervention, but not all participants receive the same combination of interventions. For example, pooled data came from studies that used a combination of exercises, environment/assistive technology, knowledge interventions, medications, and social environment [51].

In LTC, the effectiveness of exercise programs to prevent falls is still unknown due to conflicting results (may be associated with differences in interventions and resident level of dependency). However, vitamin D supplementation improved musculoskeletal function that led to moderate reductions in fall rates in LTC (37% reduction, RaR 0.63, 95% CI 0.46 to 0.86; 5 trials, 4603 participants), but there was a lack of conclusive evidence for the effectiveness of other fall prevention strategies in LTC, either single or multi-factorial [51]. A more recent systematic review and meta-analysis found that multi-factorial fall prevention programs in LTC reduced the number of falls by 33% (RR 0.67, 95% CI 0.55 to 0.82; 4 trials, 1828 participants) and recurrent fallers by 21% (RR 0.79, 95% CI 0.65 to 0.97; 4 trials, 1792 participants) [53]. However, because multi-factorial fall prevention programs were typically delivered by multi-disciplinary teams and customized to individual risk factors, implementation was challenging, time-consuming, and costly [53]. As a result, efforts to prevent fall-related injuries may be more effective than efforts to prevent falls in the LTC setting.

1.3. Interventions for preventing fall-related injuries in older adults in LTC

Efforts to prevent fall-related injuries in LTC have focused largely on fracture prevention. Recent Canadian recommendations for fracture prevention in LTC include vitamin D and calcium supplementation, use of hip protectors, exercise, multifactorial interventions to prevent falls, and pharmacologic therapies [57].

Given the serious consequences of hip fracture among residents, hip fracture prevention has been an area of focus in LTC, and studies have demonstrated that hip protectors prevent the risk of hip fracture by 77% (95% CI 0.08 to 0.67) when they are worn [58], but poor adherence is a major barrier to their effectiveness [12]. For residents with a high risk of fractures, Papaioannou and colleagues [57] estimated that vitamin D and calcium supplementation (versus vitamin D or calcium alone) may result in 15 fewer hip fractures per 1000 (95% CI 5 to 24 fewer). In addition, a reduction of five fewer hip fractures per 1000 (95% CI 2 to 8 fewer) was estimated for residents not at high risk. In addition, pharmacologic therapies showed probable reductions of 25 per 1000 hip fractures across all osteoporosis drugs (i.e., alendronate, risedronate, zoledronic acid, denosumab, raloxifene, etidronate), but found smaller reductions for raloxifene and etidronate. Pharmacologic therapies also reduced vertebral (100 per 1000) and nonvertebral fractures (20 per 1000) with all drugs, with greater reductions with teriparatide and smaller reductions with raloxifene [57].

With the rise of traumatic brain injury incidence over the past decade [34,38,39] and the majority of fall-related traumatic brain injuries believed to occur as a result of the head directly striking another surface [59–61], headgear (or helmets) are being explored. Headgear are considered a novel fall injury prevention approach to minimize the chances of sustaining a head injury, including traumatic brain injuries [34]. Purpose designed headgear aims to reduce the magnitude of impact forces sustained at the head, should the head impact a surface (e.g., floor, furniture, and wall) during a fall event. Similar to hip protectors, headgear requires user adherence from the resident and the care staff. Moreover, there is not a lot of literature available on headgear use in LTC. Future research is warranted to determine if headgear will be an accepted injury prevention strategy in LTC (i.e., by residents, staff, family members) and if it is effective at reducing traumatic brain injuries in LTC.

In light of the above evidence, and given the high probability for falls to result in injury in LTC [45], it is essential to develop new approaches for preventing all fall-related injuries in LTC, that are ideally not so dependent on user adherence, and that complement existing strategies for preventing falls.

1.4. Compliant flooring for fall injury prevention in LTC

Floors and floor coverings might also help to reduce the risk of injury in the event of fall [13]. Compliant flooring (also called ‘low stiffness flooring,’ ‘energy absorbing flooring,’ ‘safety flooring,’ ‘shock absorbing flooring,’ ‘impact absorbing flooring,’ and ‘low impact flooring’) represents a unique intervention for fall injury prevention in health care settings where individuals are particularly vulnerable to falling, including LTC. Compliant flooring decreases the stiffness of the ground surface, and the subsequent forces applied to body parts at impact when a fall occurs [62–65]. Compliant flooring has the potential to reduce the frequency of all serious fall-related injuries, including hip and wrist fractures and traumatic brain injuries. Compliant flooring represents one of the few options that may be feasible and effective for preventing fall-related traumatic brain injuries. In addition, unlike wearable hip protectors, headgear, exercise or pharmacological agents, compliant flooring is a passive form of injury prevention that (once installed) does not rely on active user compliance or adherence [66].

1.4.1. Traditional flooring provides preliminary evidence to support the concept that low stiffness floors may prevent fall-related injuries

Traditional flooring systems provided the first line of evidence to support the potential of low stiffness floors to decrease the risk of fall-related injuries. Epidemiological studies suggested that falling on a soft surface, such as padded carpet, grass, or loose dirt, would reduce the risk of sustaining a hip fracture when compared to falling on a hard surface (i.e., concrete, linoleum) [37,65]. In an acute care study, older adults who had falls on carpet were reported to have a lower rate of injury compared to falls on vinyl flooring [67]. In the laboratory, experiments provided estimates of force attenuation values during sideways falls on the hip, ranging from 7% for wooden floors, 15% for carpet, and 24% for carpet with wooden subflooring when compared to rigid flooring (concrete, vinyl) [64,65,68,69]. Additional laboratory studies reported that peak impact forces were reduced by the introduction of simple foam flooring surfaces. For example, Minns and colleagues [70] reported that peak impact force was decreased by approximately 12.5% during simulated falls on a surface covered with carpet (fabric backed luxury pile with open tufted polyester fibres) when compared to a rigid surface. By adding a 12.5 mm PVC foam underpadding to the carpet, force attenuation increased to 73% [70].

With this promising initial evidence, researchers began to conduct balance testing on simple *foam* surfaces, as compliant floors must provide sufficient impact force attenuation without increasing the risk for falling by impairing the balance and mobility of users in order to be an acceptable intervention strategy [71]. Humans control their postural stability through a complex interaction of sensorimotor processes [71–73]. For example, Wright and colleagues explain that in order to maintain upright posture during quiet stance, the vertical projection of the whole-body centre of mass must be controlled within the limits of the base of support (feet); the centre of mass trajectory is controlled through adjustments of the underfoot centre of pressure [71,72,74]. If the centre of mass shifts abruptly and anteriorly, it must decelerate by a rapid anterior shift of the centre of pressure. This initial centre of pressure response to a perturbation signifies the central nervous system's early control of balance reactions [71,75,76]. Wright et al. [71] further explain that the timing of these reactions is an important indicator of stability control and any factor that delays the onset of such reactions may increase the likelihood of falls. Compliant flooring may delay the onset of such reactions.

Compliant flooring has the potential to affect balance control by influencing the ability to generate corrective reactions (mechanical) and/or accurately detect instability (sensory) [71,77,78]. Compared to standard (rigid) surfaces, quiet stance sway increases on foam surfaces and gait shows lower centre of mass trajectories, increased strength length, increased step width, and forward pitching of the trunk [71,77,79–81]. Additionally, foam surfaces may affect the magnitude and rate of centre of pressure and centre of mass displacements during support-surface translations [66,71].

1.4.2. Biomechanical testing of novel compliant flooring systems provides promising evidence for its potential use in clinical settings

Over the last decade, compliant flooring research has shifted from exploring existing, readily available, flooring systems and materials including simple foam toward evaluating purpose-designed, novel compliant flooring (NCF). Purpose-designed compliant flooring is a padded layer, generally found beneath vinyl or carpet, usually designed to provide a dual stiffness response characterized by minimal deflection during locomotion (i.e., firm under standard loads), and a transition to increased compliance at the higher loads associated with fall-related impacts [62,63,66]. In contrast to simple *foam* surfaces, some of these NCFs do not substantially impair balance (static and dynamic) or mobility of older adults [62,66,68,71,82]. For example, few significant differences were observed between several NCFs and a rigid floor during Timed Up and Go tests [62], natural and tandem stance sway [62,82], a posterior floor-translation perturbation [62,66], and initial dynamic balance response following a lean-and-release perturbation [71]. Laboratory studies have also demonstrated that purpose-designed compliant flooring can reduce the peak force applied to the hip during a simulated sideways fall by up to 35% [62,68] and to the head during a simulated backwards fall by up to 60% [61]. Compliant flooring is particularly effective at reducing the impact forces to hip among adults with low body mass index, such as frail older adults in LTC [83–85].

However, compliant flooring may increase rolling resistance versus standard flooring (e.g., concrete) because of its low stiffness and susceptibility to deform under a load [68]. Thus, compliant flooring may increase physical demands for health care workers and may pose health and safety risks for them. Although some evidence suggests that compliant flooring increases comfort and reduces perceptions of fatigue due to underfoot impact among health care workers, more evidence suggests that compliant flooring makes it more difficult for workers to perform tasks, including maneuvering equipment (e.g., floor-based lifts, wheelchairs, beds/patient trolleys), compared to standard flooring [86–92].

1.4.3. Early clinical findings further support the potential role of novel compliant flooring to prevent fall-related injuries

Preliminary clinical findings suggest that compliant flooring may reduce fall-related injuries in LTC [88,93,94]. A 2.5-year retrospective cohort study at an American LTC site found there was a non-significant trend for fewer bruises and abrasions from falls on compliant flooring (2.54 cm SmartCells installed in two resident bedrooms and bathrooms) than falls on standard flooring [94]. While two falls on standard flooring resulted in fracture, no falls on compliant flooring resulted in fracture [94]. Further, a non-randomized control study of women residents at a Swedish LTC site installed compliant flooring (1.25 cm Kradal) in 350 m^2 of a single ward, including some resident rooms and common areas but no bathrooms [95]. During 2.5 years of prospective falls surveillance, 16.9% of falls (13 of 77) on compliant flooring were injurious compared to 30.3% of falls (77 of 254) on control flooring (vinyl, linoleum, and ceramic tile all with concrete underlay), which resulted in a significant 59% reduction (95% CI 20 to 80%) in risk for fall-related injury after adjustment for individual-level covariates; however, 80% of fall-related injuries were of minor severity (e.g., distinct pain, bruising, swelling), and there was insufficient statistical power to test the effect of compliant flooring on more serious fall-related injuries [95].

Preliminary findings also suggest that compliant flooring may reduce fall-related injuries in acute care settings [86,93]. In an unblinded, pilot cluster randomized controlled trial in the United Kingdom, geriatric wards at eight acute care facilities were allocated to compliant (8.3 mm vinyl Tarkett Omnisports EXCEL) or control (standard) flooring [86]. During one year of outcome monitoring, 23% of falls (8 of 35) were injurious in intervention wards compared to 42% of falls (14 of 33) in control wards, which resulted in a non-significant change of 42% (IRR: 0.58; 95% CI: 0.18 to 1.91) in the incidence of fall-related injuries. No moderate or major severity injuries occurred in intervention wards, while six occurred in control wards [86]. In a non-randomized study at a New Zealand acute care facility, three types of compliant flooring were installed in a total of six bedrooms (with a total of 12 beds) on a single ward [93]. Over 6 months, 40.4% of falls (21 of 52) on standard flooring were injurious compared to 23.8% (5 of 21) on compliant flooring [93].

Coinciding with the clinical studies that have been conducted in recent years, researchers have also begun to investigate whether compliant flooring is a cost-effective strategy. Reports from the literature suggest that materials and installation of compliant flooring systems cost more than standard flooring [62,96–100]. Nevertheless, preliminary cost-effectiveness studies which compare costs of compliant flooring to health care savings that could be realized by the injury prevention capabilities of compliant flooring provide some indications that compliant flooring may be a cost-effective strategy for LTC and acute care settings (assumption: 40-67% injury reduction; RR range: 0.33 – 0.60) [62,96–100].

1.4.4. Gaps in the literature on compliant flooring

The above evidence suggests that compliant flooring may be an effective intervention for preventing fall-related injuries in LTC and acute care settings, but the number of falls and fall-related injuries observed within individual studies have been small, precluding definitive conclusions. In the LTC environment in particular, no randomized controlled trial has been sufficiently powered to test the effectiveness of compliant flooring for reducing fall-related injuries in LTC. Such evidence is needed to inform fall-injury prevention strategies in LTC and to aid in the design of new and safer sites.

The ongoing Flooring for Injury Prevention (FLIP) Study is a 4-year randomized controlled trial designed to address this gap [101]. Intervention (2.54 cm SmartCells compliant; 74 rooms) and control (2.54 cm plywood; 76 rooms) flooring were installed over the top of existing concrete floors and covered with identical 2.00 mm vinyl. The trial will determine if compliant flooring is effective at reducing the number and severity of fall-related injuries in a LTC setting (clinical effectiveness) as well as reducing the health resource utilization and costs of fall-related injuries (cost-effectiveness) [101].

In addition to determining the clinical and cost-effectiveness of compliant flooring, it is also essential to explore the feasibility of implementing compliant flooring in LTC to inform and support decisions about fall injury prevention. I considered compliant flooring to be a feasible intervention if stakeholders responsible for fall injury prevention in LTC were enthusiastic about the proposed intervention and could potentially champion the implementation of compliant flooring if the randomized controlled trial data showed it to be clinically and cost effective, and if installations of compliant flooring would not harm LTC staff. Consistent with the integrative knowledge translation approach [102], I involved stakeholders across several disciplines (e.g., health care, industry, and research) throughout the research process to ensure the findings were as relevant to, and thus more likely to be useful to, key stakeholders. These stakeholders were also involved in my 'end-of-grant' knowledge translation and dissemination strategies (e.g., stakeholder symposium).

1.5. Conceptual Model: Borrowing from the Knowledge-to-Action Cycle

Acknowledging the need to explore the feasibility of implementing compliant flooring, I used the Knowledge-to-Action (KTA) cycle as a way to conceptualize my thesis (**Figure 1.1**) [103,104]. The KTA cycle is a widely accepted framework that was developed based on the review of more than 30 planned action theories. The KTA cycle helps theorize ways to address evidence-practice gaps and support uptake of knowledge in practice settings. Specifically, the KTA cycle is an iterative, dynamic, and complex process concerning knowledge creation and knowledge application (action cycle) whereby the boundaries between the creation and action components are fluid and permeable [105].

The knowledge creation section is a funnel that contains the major action steps of the KTA model, including the knowledge inquiry, knowledge synthesis, and knowledge product/tools phases [104]. The knowledge inquiry phase represents all of the primary studies or information that is in the research community, regardless of its accessibility (i.e., first generation knowledge) [104,106]. When considering compliant flooring research, this would include any primary studies that examined topics like biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety of compliant flooring. Next, knowledge synthesis (i.e., second generation knowledge) represents the aggregation of existing knowledge on a particular topic in the form of scoping reviews, systematic reviews, meta-analyses, and network meta-analyses. These reviews are the basis for the knowledge products/tools phase (i.e., third-generation knowledge) that refines the knowledge into manageable units (e.g., clinical practice guidelines for health care professionals, decision aids for patients, policy briefs for decision makers) [104,106,107].

The action cycle identifies seven action phases that represent the activities and process related to the use or application of knowledge; these phases can occur sequentially or simultaneously and the knowledge creation phases can influence the action cycle phases at any point in the cycle (**Figure 1.1**) [104,106]. The action phases include the steps required to implement knowledge in health care settings, including identification of the problem; identification, selection and review of the knowledge (to implement); adaptation of the knowledge to the local context; assessment of the determinants (barriers, facilitators) to using the knowledge; selection and implementation of interventions to promote the knowledge; monitoring knowledge use; evaluation of the outcomes or impact using the knowledge; and determining strategies for ensuring sustained knowledge use. Consistent with the cycle's presumptions, I involved key stakeholders of compliant flooring throughout my thesis research to ensure that my research findings were relevant to their needs [106].

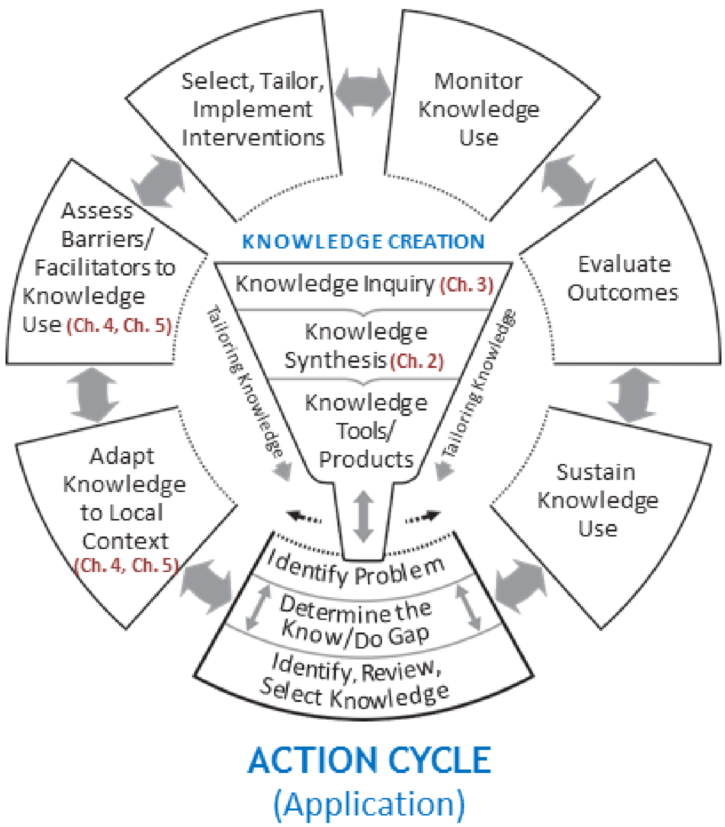

Figure 1.1 The conceptual model of my thesis research
This figure is adapted from the Knowledge-to-Action Cycle from: Graham, I. D., Logan, J., Harrison, M. B., Straus, S. E., Tetroe, J., Caswell, W., & Robinson, N. (2006). Lost in knowledge translation: time for a map? Journal of continuing education in the health professions, 26(1), 13-24.

1.6. Knowledge translation initiatives in LTC

Effective knowledge translation and dissemination is essential to increase the availability of health information and enhance resident safety [108]. However, the transfer of new knowledge into practice is slow, if disseminated at all [109]. Therefore, the assessment of barriers and facilitators to knowledge use is an important step in ensuring successful knowledge translation [108]. The Clinical Practice Guidelines Framework is one of the most cited conceptual frameworks regarding barriers to knowledge use in health care [108]. The extended version of the Framework aims to standardize the reporting of barriers and facilitators to knowledge use in the health care context across different studies [108]. The authors define a barrier as factors that would limit or restrict implementation of shared decision making in clinical practice and a facilitator as factors that would promote or help implement shared decision making in clinical practice [108,110]. The same factor can be a barrier and a facilitator. A highly referenced systematic review of barriers and facilitators to implementing shared decision making in clinical practice identified an extensive list of barriers and facilitators under three main categories: knowledge (e.g., lack of awareness), attitudes (e.g., lack of motivation), and behaviour (e.g., factors associated with environmental factors, such as lack of resources) [111]. This review can be used as a guide when considering barriers and facilitators to knowledge use [111].

Despite the increasing amount of knowledge translation being conducted in health care, the state of knowledge translation in the care of older adults is underdeveloped [109]. A recent scoping review revealed only two of 53 systematic reviews specifically targeted to KT research were relevant to older adults [109]. Further, only 30 (1.8%) of 1709 primary research articles were conducted in LTC [109], and these primarily focused on knowledge translation interventions, which are conducted when there is clear evidence that an intervention is effective. Professional interventions (e.g., education of physicians or staff, educational outreach, audit and feedback) were identified in the scoping review as the most common (53%, 31 records). The goal of such knowledge translation interventions is to facilitate the uptake of research into practice and/or policy (i.e., beyond the knowledge creation stage) [112].

To my knowledge, early-stage knowledge translation studies in LTC are lacking. My thesis takes a novel approach by translating knowledge about compliant flooring to stakeholders at an earlier stage in the KTA Framework, before clinical and cost-effectiveness has been established. Conducting early-stage knowledge translation studies, in tandem with the conduct of clinical and cost-effectiveness trials, should improve future dissemination of trial findings and implementation of compliant flooring, if appropriate, and improve the design of future trials. Together, these actions will aid in closing the knowledge to practice gap that often transpires in clinical research [103]. By narrowing the gap from knowledge to practice, we may have an increased opportunity to reduce the rates of fall-related injuries in LTC at a faster pace, decreasing the health care dollars spent on the falls epidemic.

1.7. Specific aims of the thesis

The overall goal of my thesis is to provide a comprehensive evaluation of compliant flooring to help determine whether it is a feasible strategy for fall injury prevention in the LTC environment. Compliant flooring will be considered a feasible intervention if stakeholders responsible for fall injury prevention in LTC are enthusiastic about the proposed intervention and could potentially champion the implementation of compliant flooring if the randomized controlled trial data showed it to be clinically and cost effective, and if installations of compliant flooring would not harm LTC staff. Specifically, I investigate the feasibility of compliant flooring for LTC by synthesizing the available evidence (knowledge synthesis; Chapter 2) and determining effects of compliant flooring on forces required for LTC staff to push wheeled equipment (knowledge inquiry; Chapter 3). These studies provide fundamental information about compliant flooring, but they did not specifically examine the perceptions of key stakeholders who would be involved in the decision making of implementing compliant flooring. Informed by the results of Chapters 2 and 3, I adapted the current knowledge to local context via a brief script to inform senior managers about compliant flooring and examined the barriers to and facilitators of implementing compliant flooring in LTC as perceived by LTC senior managers involved in fall injury prevention efforts (action cycle; Chapter 4). Building on this work, I then adapted the knowledge gained from Chapters 2 through 4 to the local context via podium presentations to inform knowledge users from health care, industry, and research about compliant flooring (action cycle; Chapter 5). I then conducted a workshop to solicit the barriers to and facilitators of implementing compliant flooring in LTC as perceived by this broad range of stakeholders involved in LTC fall injury prevention efforts (action cycle; Chapter 5). Overall, my thesis will help to inform ways to select, tailor, and implement future knowledge translation interventions to facilitate the uptake of fall injury prevention strategies, such as compliant flooring, and may serve as a model for other knowledge uptake efforts within LTC.

1.7.1. Chapter 2 – a scoping review

Concise rationale

Health care decision makers tasked with preventing fall-related injuries in older adults who I have surveyed state that one barrier to uptake compliant flooring is a lack of synthesized evidence about key performance aspects of compliant flooring systems. However, there is no published review that has summarized the evidence about compliant flooring for health care decision makers.

Aims

To conduct a scoping review to determine what is presented in the scientific literature about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems that aim to prevent fall-related injuries in health care settings. The specific objectives are to (i) describe the extent, range, and nature of research activity, and (ii) identify research gaps in the current knowledge and directions for future research about compliant flooring.

Contribution

With stakeholder involvement throughout the entire research process, this scoping review provides key deliverables that are important for the targeted knowledge users. Specifically, in the short-term, the study summarizes the available evidence about compliant flooring as a potential intervention for preventing fall-related injuries in older adults, and it identifies gaps in evidence and new avenues for research. In the long-term, the study will help support decisions related to fall injury prevention in LTC and other health settings (e.g., acute care, home care, assisted living) and inform the design of safer environments for vulnerable older adults.

1.7.2. Chapter 3 – an ergonomic evaluation

Rationale

To be a feasible intervention in LTC, compliant flooring must decrease the risk of fall-related injuries for residents without increasing the risk of musculoskeletal injury for care staff when performing regular job duties. Because of its low stiffness and susceptibility to deform under load, compliant flooring increases rolling resistance versus standard flooring (e.g., concrete).

Accordingly, there is specific concern that maneuvering floor-based lifts on compliant flooring may expose LTC staff to potentially injurious forces, which would pose an important barrier to the uptake of compliant flooring in LTC.

Aims

To conduct experiments to (a) determine the effects of flooring system (concrete+vinyl, compliant+vinyl, concrete+carpet, compliant+carpet), and resident weight (average, 90th percentile) on (i) the external hand forces required for LTC direct-care staff to push floor-based lifts (conventional, motor-driven) and (ii) subjective ratings of pushing difficulty and to determine if these effects are modified by lift type and (b) compare forces from each experimental condition to recommended limits for tolerable pushing.

Contribution

This study provides new knowledge about the effects of compliant flooring and a novel motor-driven lift on forces during pushing tasks in LTC. I demonstrate that compliant flooring increases initial and sustained push forces and subjective ratings compared to concrete flooring. However, compared to the conventional lift, the motor-driven lift substantially reduces these forces and may help to address risk of work-related musculoskeletal injury, especially in locations with compliant flooring.

1.7.3. Chapter 4 – an interview study

Concise rationale

For widespread implementation of compliant flooring in LTC, several key stakeholders must accept and support the intervention, including LTC senior managers. But, there is paucity of knowledge about the perceived value of compliant flooring among such stakeholders involved in decision making about fall injury prevention.

Aims

To solicit the opinions of key organizational-level stakeholders (i.e., LTC senior managers) on the perceived feasibility of compliant flooring as a fall injury prevention strategy within LTC.

Contribution

The interview findings support the importance of seeking input from stakeholders about the feasibility of compliant flooring. The findings provide new evidence about important facilitators and barriers that stakeholders consider in deciding to install compliant flooring in LTC, such as staff's openness (or resistance) to change and flooring performance. The findings also suggest an opportunity for knowledge translation and dissemination efforts to inform LTC senior managers about the currently available evidence on compliant flooring.

1.7.4. Chapter 5 – a stakeholder symposium

Concise rationale

Compliant flooring must be accepted by stakeholders from health care, industry, and research before it is accepted as a feasible strategy for fall injury prevention. In chapter 4, I discover new insights about compliant flooring from the perspectives of LTC senior managers, but the perceived value of compliant flooring among other key stakeholders is still unknown, including: clinicians, allied health practitioners, researchers, interior designers, industry partners, health managers and regulators.

Aims

To identify the perspective of key stakeholders on the advantages and disadvantages of implementing compliant flooring in LTC, and the most pressing research gaps and directions for future research on compliant flooring. As a secondary objective, I gathered feedback on the usefulness of a stakeholder symposium format as a knowledge translation activity.

Contribution

I conduct a knowledge translation event to explore the perceptions of key stakeholders about implementing compliant flooring in LTC. My findings suggest that while stakeholders perceive compliant flooring to add value to the LTC setting, there also remain significant informational and financial barriers to the uptake of compliant flooring. I provide suggestions for future research based on the stakeholders' input.

Chapter 2. Compliant Flooring to Prevent Fall-Related Injuries in Older Adults: A Scoping Review of Biomechanical Efficacy, Clinical Effectiveness, Cost-Effectiveness, and Workplace Safety

2.1. Introduction

Falls are the leading cause of injury-related hospitalization and death among seniors and are responsible for annual direct costs of $3.4 billion in Canada and $34 billion in the United States [1,113,114]. Aside from death, hip fracture and traumatic brain injury (TBI) are the most serious fall-related injuries and are associated with lasting and devastating consequences, including loss of independence, reduced quality of life, and premature mortality [23].

The long-term care (LTC) setting is an especially high-risk environment for falls and fall-related injuries. Approximately 60% of LTC residents fall at least once per year, and 30% of falls in LTC cause injury, rates that are two to three times higher than for community-dwelling older adults [16–19,115]. In fact, LTC residents are ten times more likely to sustain a hip fracture than community-dwelling older adults [17,45], and following hospitalization for hip fracture, 25% of LTC residents die within six months and less than 50% of LTC residents regain their pre-injury ambulation status [18,30,31]. Furthermore, TBIs have tripled in incidence over the past decade and account for almost half of fatal falls in LTC residents [18,34]. One quarter of fall-related TBIs in older adults occur in LTC sites [34,38,39]. The majority of fall-related TBIs are believed to occur as a result of the head directly striking another surface; thus, the severity of fall-related TBIs is influenced by the mechanical properties of the impact surface [61,116,117].

Preventing falls and fall-related injuries among older adults in LTC remains a significant challenge, in part because LTC residents often present with compromised physical and cognitive function [51,53,54]. A recent Cochrane systematic review showed vitamin D supplementation leads to small reductions in fall rates in LTC, but concluded there is insufficient evidence to comment on the potential effectiveness of other single or multi-factorial fall prevention strategies in the LTC setting, including environmental, exercise, pharmaceutical, and administrative interventions [51]. When considering injury prevention strategies, evidence suggests hip protectors reduce the risk of hip fracture by close to 80% when they are worn at the time of a fall;

however, hip protectors only protect one impact site and poor adherence is a major barrier to effectiveness [58,118–120]. Given the public health and individual burden caused by fall-related injuries in LTC, it is essential to develop new and effective strategies for preventing fall-related injuries.

A promising strategy is to decrease the stiffness of the ground surface, and the subsequent forces applied to the body at impact, by installing compliant flooring, a passive intervention approach that (once installed) does not rely on user adherence [61]. Unlike hip protectors, compliant flooring has the potential to reduce the frequency of all fall-related injuries, including hip and wrist fractures and TBIs [101]. If effective, compliant flooring should be most beneficial in high-risk environments such as LTC. However, few LTC sites have implemented flooring systems specifically designed to reduce the severity of fall impacts [101]. Health care decision makers who we have surveyed state that one barrier to uptake is a lack of synthesized evidence about key performance aspects of compliant flooring systems.

Indeed, a 2010 rapid report published by the Canadian Agency for Drugs and Technologies in Health [121] concluded that no relevant health technology reports, systematic reviews, meta-analyses, randomized controlled trials, non-randomized studies, or economic evaluations were found on the use of rubberized flooring in LTC to prevent or minimize fractures due to falls. That report focused exclusively on the clinical effectiveness of compliant flooring in LTC. A more comprehensive review of the currently available literature on compliant flooring is required to inform fall-related injury reduction strategies in LTC and other high-risk health care settings [121].

Thus, to inform fall-related injury prevention strategies in LTC, we conducted a scoping review to address the following research question: what is presented in the scientific literature about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems that aim to prevent fall-related injuries (as defined in **Table 2.1**)? Our specific objectives were to (i) to describe the extent, range, and nature of research activity, and (ii) identify gaps in the current knowledge and directions for future research about compliant flooring. The summary of evidence in this review will be especially useful in LTC, but also applicable in acute care, assisted living, hospice, and home care environments.

2.2. Methods

Accordingly, we followed the 6-stage scoping review framework of Arksey and O'Malley [122] and incorporated the published amendments to it [123–126]. The scoping review methodology was particularly well-matched to the research question because the use of compliant flooring for fall-related injury prevention is an emerging research area, the study objectives were defined broadly and exploratory in nature, and relevant evidence originates from published and unpublished sources from a variety of disciplines (e.g., biomedical engineering, epidemiology, health economics, ergonomics) and study designs in both published and grey literature [125,126].

2.2.1. Identifying the research question

Our research question was designed to generate breadth of coverage [122], and was developed originally by core members of the research team (CCL, DCM). It was then reviewed at a Planning Meeting with other members of the research team and by the study's Research Advisory Panel (composed of knowledge users) to further refine the types of information about compliant flooring that were of highest importance to knowledge users and researchers. The Panel input also helped develop the definition of compliant flooring systems and the four thematic areas of interest: biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety (**Table 2.1**).

2.2.2. Identifying relevant records

Licensed academic databases

We conducted academic database searches from inception to the 30th of September 2015 in AgeLine, CINAHL Complete, EBM Reviews (includes CENTRAL, Cochrane Database of Systematic Reviews, and DARE), Ergo-Abs (Ergonomics Abstracts), MEDLINE [Ovid], SPORTDiscus, and Web of Science (**Table 2.2**). The main concepts of our research question (i.e., flooring, biomechanical efficacy, clinical effectiveness, cost-effectiveness and workplace safety) were expressed through a combination of keyword synonyms, related terms, and controlled vocabulary terms (e.g., MeSH). An information scientist (ACD) oversaw development of our initial search strategy in MEDLINE[Ovid] and subsequent modifications for each database searched, according to the required syntax and search limitations of each database. The final

MEDLINE [Ovid] search string (**Table A1 in Appendix A**) also informed the approach to grey literature searching. We received monthly alerts from each database of all records captured in our search string that were uploaded online after our baseline search (i.e., after 30th of September 2015 through to our cut-off date of 20th of May 2016). All records identified through licensed electronic database searching were saved to RefWorks, an online citation management software, and duplicate citations were removed.

Table 2.1 Key concepts and definitions pertaining to the study research question

Concept	Definition
Compliant Flooring Systems	Broadly defined as flooring systems or floorcoverings with some level of shock absorbency, for example, safety flooring, shock absorbing flooring, dual stiffness flooring, rubber flooring, acoustic flooring, and carpet.
Biomechanical Efficacy	Evidence from experiments conducted in a controlled, laboratory environment about (i) impact force attenuation or energy absorption during real or simulated falls onto compliant flooring systems, or (ii) balance, gait and mobility performance, and/or, assistive device use on compliant flooring systems.
Clinical effectiveness	Evidence from research involving human participants and measurement of how compliant flooring systems affect fall-related injuries and falls.
Cost-effectiveness	Evidence related to the costs of compliant flooring systems relative to their effects on fall and fall-related injury health care costs.
Workplace Safety	Evidence about the effects of compliant flooring systems on musculoskeletal health and fatigue of health care workers as a direct result of differences in floor compliance.
Fall-related injury	Broadly defined as fractures or soft tissue injuries (e.g., haematoma, traumatic brain injury, dislocation, laceration/cut, sprain/strain, contusion/bruise, swelling, pain) as a direct result of impact from a fall [101].

Table 2.2 Sources of academic and grey literature

Search Type (Date range searched)	Sources of Literature
Academic Search (Inception to present)	AgeLine [EBSCO; 1978 - present] CINAHL Complete [EBSCO; 1937 - present] EBM Reviews [OVID; 1991 - present] Ergo-Abs [Ergonomics Abstracts, EBSCO; 1985 - present] MEDLINE [Ovid; 1950 - present] SPORTDiscus [EBSCO; 1830 - present] Web of Science [Thomson Reuters; 1898 – present]
Grey Literature Search (1990 to present)	Clinical trial registries: - Clinicaltrials.gov - Controlled-trials.com Theses/Dissertations: - ProQuest Theses and Dissertations Abstracts/Conference Proceedings for target associations: *Bioengineering* - Annual Conference of the IEEE Engineering in Medicine and Biology Society - ASME Summer Bioengineering Conference *Biomechanics* - Annual Conference of the American Society of Biomechanics - Biennial Meeting of the Canadian Society of Biomechanics - Congress of the International Society of Biomechanics *Falls Prevention* - Biennial Conference of the Australian and New Zealand Falls Prevention Society - International Conference on Fall Prevention and Protection - International Society for Posture and Gait Research World Congress *Gerontology* - Canadian Association on Gerontology Annual Scientific and Educational Meeting - Gerontological Society of America's Annual Scientific Meeting - World Conference of Gerontechnology - World Congress of the International Association of Gerontology and Geriatrics Websites of target organizations: - Agency for Health care Research and Quality (AHRQ) - American Society for Testing and Materials (ASTM) International - Canadian Agency for Drugs and Technologies in Health (CADTH) - Occupational Safety and Health Administration (OSHA) - OpenSIGLE - Parachute Canada - The National Institute for Occupational Safety and Health (NIOSH) - UK Health Technology Assessment - US Center for Health Design - World Health Organization (WHO) Health Evidence Database (HEN)
Hand Searching (1990 to present, if warranted)	Reference lists of all eligible records Tables of contents of 1-2 key journals
Consultation with experts (N/A)	We consulted with content experts and the Research Advisory Panel to identify individual records not already uncovered by our academic database, grey literature, and hand searches.

Grey literature

We conducted a targeted search of grey literature to identify clinical trials, abstracts and conference proceedings from pertinent scientific meetings, as well as theses, dissertations and reports not indexed in licensed academic databases (**Table 2.2**). The selected sources of grey literature were chosen by content experts on the research team, in consultation with knowledge users on the Research Advisory Panel. We implemented a variety of search strategies to obtain relevant records from each source, including manually screening titles, Google advanced search, Adobe Reader advanced search and website search engines. We kept our search terms intentionally broad (e.g., floor, surface, elder, senior, fall, injury) to keep this initial grey literature search as inclusive as possible.

Hand searching and consultation with experts

The references from all records that are identified for inclusion in our review were manually reviewed. We also hand searched the table of contents of Age and Ageing, which was the journal that yielded the most included records. We also consulted with the Research Advisory Panel and content experts to uncover additional relevant literature.

2.2.3. Identifying relevant records

Eligibility criteria

We included any records which described the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety of compliant flooring systems that aim to prevent fall-related injuries (**Table 2.1**). Records were selected according to the criteria below [127].

Designs. Consistent with scoping review methodology, we considered all methodological designs (i.e., primary and secondary research), including published and unpublished records of quantitative, qualitative, or mixed-methods research design. We excluded marketing materials from flooring manufacturers, such as product guides, or studies conducted directly by manufacturers as they may present biased information.

Participants. We included records that had human participants 18 years of age or older (e.g., university students, older adults). We also included laboratory tests of compliant flooring, economic analyses, and other records that may not involve human participants. We excluded all records that exclusively examined animals, children/teens (0 – 17 years), or athletes (all ages), since the Research Advisory Panel agreed that evidence from these populations would be unlikely to influence decisions to adopt compliant flooring in health care settings for older adults.

Interventions. We included records if they examine any of the flooring types included in our definition of 'compliant flooring systems'. This includes: safety flooring, shock absorbing flooring, dual stiffness flooring, rubber flooring, acoustic flooring, and carpet. Fall mats were not considered a compliant flooring system for several reasons: they are not permanently affixed to the floor; they do not provide universal coverage or protection; and they are considered to be programmatic equipment. Thus, studies reporting exclusively on fall mats were not eligible.

Comparators. We included a variety of rigid flooring conditions as comparators (e.g., concrete, thin vinyl, force plate).

Outcomes. Outcomes of interest varied depending on the theme(s) of the record. We considered (but did not necessarily limit to) the following outcomes for each theme:

Biomechanical efficacy: we considered records that report evidence from laboratory research about (i) impact force attenuation or energy absorption during real or simulated falls onto compliant flooring systems, or (ii) gait performance, mobility performance, assistive device use and/or balance on compliant flooring systems.

Clinical effectiveness: we considered records that examine how compliant flooring systems affect falls and fall-related injuries.

Cost-effectiveness: we considered records that provide evidence related to the cost of compliant flooring systems (e.g., material and installation costs, longevity of flooring) relative to their effects on fall and fall-related injury health care costs.

Workplace safety: we considered records that provide evidence about the effects of compliant flooring systems on musculoskeletal health and fatigue of health care workers as a direct result of differences in floor compliance. Records may include perceived/subjective ratings of systemic and musculoskeletal fatigue or objective measures of fatigue (e.g., via physiological sampling) while working on compliant flooring. We will not include records reporting on workplace hazards/safety associated with floor traction or floor slipperiness.

Setting. Records were included if the research was conducted in a laboratory, community or relevant health care setting (e.g., acute care, assisted living, LTC). Consistent with our population exclusion criteria, we excluded records if the research was conducted within a sporting, playground, school, or pediatric acute care setting.

Timing and Language. We did not limit our academic database search by year or language of publication. For records not available in English, we used Google Translate, when necessary. For feasibility reasons, we limited our grey literature search to records published in English after 1990 (i.e., when the first academic records on the biomechanical efficacy of compliant flooring were published).

2.2.4. Selection process

We selected relevant records using a two-step process: (i) review titles and abstracts (level 1 screening) and (ii) review full-text records (level 2 screening). We used a hierarchical approach when screening records. We first excluded records if they are marketing materials or if they described research exclusively involving animals. Next, we excluded records that do not include at least one type of compliant flooring system; and then we excluded records that did not address one of the four themes. Lastly, we excluded records if the population of interest was exclusively children and/or athletes. Pilot testing occurred before each screening stage to refine the screening spreadsheets and key definitions, which improved inter-rater agreement. The two reviewers met at regular intervals to resolve discrepancies, and involved a third reviewer (DCM) to help settle unresolved discrepancies.

Level 1 screening of licensed academic databases (titles and abstracts)

Two reviewers (CCL, MPJ) independently screened the titles, abstracts and descriptors based on the defined eligibility criteria using a level 1 screening form. Screening was performed in batches of approximately 700 and discrepancies were identified by an independent research assistant and resolved by the two primary reviewers, with help from a third when necessary, after the completion of each batch. This allowed us to periodically identify and correct any systematic differences in application of the eligibility criteria between the two reviewers. In situations when there was not enough information to make an informed decision about inclusion/exclusion, the record was retained for level 2 screening. To further increase the study's rigor, a third reviewer (DCM) re-screened 5% of records excluded by the other two reviewers to confirm that eligibility criteria were applied appropriately.

Level 2 screening of licensed academic databases (full-text review)

Full-texts of all records that pass level 1 screening were retrieved, and we applied the same inclusion/exclusion criteria. We again performed a pilot test, this time with 20 records. Records were then independently screened by both reviewers in batches of 50. Discrepancies were identified by an independent research assistant and resolved by the two primary reviewers, with help from a third when necessary, after the completion of each batch. Reviewers also categorized records into the four themes at this stage.

Grey literature screening

We also performed grey literature screening in two stages. First, one reviewer (MPJ) searched grey literature sources for relevant records and selected all records that appeared to match the eligibility criteria. Next, a second reviewer (CCL) screened the included records for any other necessary exclusion. We resolved disagreements by discussion amongst the two reviewers and involved a third reviewer (DCM) as needed.

Once all eligible records were obtained, we identified companion records by matching the authors, compliant flooring intervention (if applicable), and timeframe that the study was conducted, an approach adapted from Tricco and colleagues [128]. We designated the main record as the one which provided the most detail about the study and the companion report(s) was included for descriptive purposes only. For example, an original article would be designated as the main record while a corresponding conference abstract or review article citing the original article would be deemed a companion record.

2.2.5. Charting the data

Following level 2 screening, we categorized included records into the four pre-specified themes, according to their primary theme, which helped to guide the outcomes obtained during the charting process. Two reviewers (CCL, MPJ) independently charted data from all main records using a pilot-tested electronic spreadsheet to extract key information from full-text records that passed level 2 screening (**Table 2.3**). The two reviewers met after charting each theme to review entries and resolve discrepancies and involved a third reviewer (DCM) as needed. Charted information included: (1) Record summary (citation details, type of record, theme, and objectives); (2) Methods (location, setting, design, population of interest, sample, and flooring interventions and comparators); and (3) Findings (results, conclusions, limitations, and suggestions for future research). We also classified records as either academic or grey literature reports, as our academic database searches, reference list searches and consultation with content experts generated both types of literature. We imported and managed records in Refworks.

The research team acknowledged there was a large potential for discrepancy at this stage, and therefore several strategies were used to improve consistency of charting. First, where possible, drop down menus were used in data entry spreadsheets (i.e., data validation) to avoid trivial discrepancies such as punctuation differences. Second, sections of records from which large amounts of data were collected (e.g., research aims, results, conclusions, suggestions for future research, etc.) present a particularly high chance of inter-rater discrepancy; thus, where possible, we transposed these data exactly as they exist in the original record. Finally, we stated the results and conclusions in terms of the author’s research aims. When comparing discrepancies in these sections, the reviewers looked for differences in content only and recorded all relevant data from both entries into one master copy.

Table 2.3 Data extraction for research question

Section	Data to be extracted
Summary	Record title Author(s) Year of publication Journal title Type of record (original article, systematic review, non-systematic review, conference proceeding, abstract, case report, brief report, thesis/dissertation, clinical trial registration, editorial/opinion piece, book/book chapter, case report, other) Which theme(s) does the record address (biomechanical efficacy, clinical effectiveness, cost-effectiveness, workplace safety)? Research aims
Methods	Location where research was conducted (country) Setting (type: laboratory, community, acute care/hospital, assisted living, long-term care, other; description of setting: size, specialization) Design (randomized controlled trial, non-randomized controlled trial, non-randomized uncontrolled trial, prospective cohort study, retrospective cohort study, meta-analysis, systematic review, non-systematic review, qualitative methods/qualitative study, controlled experiment, simulation study, modeling study, other) Population [adults – workers (18 - 64 years), adults – university students (18 – 64 years), older adults (65+ years), other] Sample size (total number of participants, number of participants in intervention group, number of participants in control group) Description of participants (age, sex, inclusion/exclusion criteria) Intervention types Comparators Flooring system, e.g., vinyl (>0.2 cm), carpet (standard), carpet tile, Sorbashock, Forbo, Tarkett Omnisports EXCEL, DAX Tatami Martial Arts, SmartCells, Landsafe, Kradal, SofTile Term used for compliant flooring Is this record's primary focus related to compliant flooring? Outcome measures Definition(s) of fall-related injury
Results and Future Directions	Abstract results Important results Abstract conclusions Authors' conclusions Authors' criticisms of their research Authors' suggestions for future research Authors' conflict of interest statement

2.2.6. Collating, summarizing and reporting the results

We summarized the results of the scoping review using both numerical (quantitative) and narrative (qualitative) analysis to describe the extent, range, and nature of research activity. Our numerical analysis mapped the records in terms of year of publication, country of origin, source (e.g., licensed academic databases vs. grey literature), methodology, and key themes (i.e., biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety). For the narrative analysis, we coded results and conclusions of each charted record according to the question they addressed and the effect they reported (e.g., reduced impact forces, increased fall risk, etc.). The authors' suggestions for future research in the included records, complemented by our consultations with the Research Advisory Panel, were used to inform the research gaps and avenues for future research in this manuscript. In our manuscript, we use the term 'evidence' to refer to research activity in a particular area, and more specifically, to records that described the topic of interest; we do not use 'evidence' as a synonym for statistically significant results.

2.2.7. Consulting with stakeholders

Our review was informed at each stage by iterative consultations [i.e., in-person group meetings (with teleconferencing available for members unable to attend on site) and email correspondence] with a range of potential knowledge users. Specifically, we have formed a Research Advisory Panel composed of the following knowledge users: two Managers of fall and injury prevention for local health authorities, two Directors of Care at LTC sites, a physiotherapist at a LTC site, and two representatives from Lower Mainland Facilities Management, which manages all infrastructure projects for the four Lower Mainland health authorities in British Columbia. Collectively, members of the Panel possess the relevant expertise and decision making authority to critically evaluate and implement compliant flooring systems in high-risk environments such as LTC. The Panel was involved on a consultancy basis with: (i) developing the research question and key definitions integral to the review (group meeting 1; **Table 2.1**), (ii) providing feedback on the design and implementation of the review (group meeting 2); (iii) helping to interpret findings and research gaps (group meeting 3); and (iv) strategizing ways to disseminate the review's findings (group meeting 3). In addition to the in-person group meetings, the research team provided updates to Panel members on a semi-regular basis (i.e., every 2-3 months) through email correspondence, which enabled the Panel to provide feedback.

2.3. Results

The original academic database searches conducted from inception to September 30, 2015 yielded 4894 records (**Figure 2.1**, summary of the record selection process). After removing duplicate records (n = 1283), we identified 3611 records for level 1 screening (title and abstract review). Of these, we excluded 3445 records and selected 166 for level 2 screening (full text review). After full text screening, 65 records from our academic database search reported on compliant flooring and at least one of our four themes and were thus included (101 records were excluded). Grey literature searches, hand searching techniques, consultation with content experts, and post-baseline academic searches yielded an additional 75 records. Therefore, when considering all search strategies, 140 records met our inclusion criteria. Of these, 84 main records (53 academic records, 31 grey literature records) were charted using our data charting spreadsheet, while 56 were included as companion records for descriptive purposes only (**Appendix B**). We then categorized each of the 84 charted records into the four themes: biomechanical efficacy (n = 50), clinical effectiveness (n = 20), cost-effectiveness (n = 12), and workplace safety (n = 17). Fourteen records were categorized under more than one theme. Inter-rater agreement for selection of articles during level 1 and level 2 screening was good (k = 0.85, 95% CI 0.83 to 0.87 and k = 0.69, 95% CI 0.63 to 0.75, respectively). The third reviewer (DCM) who re-screened 5% of all records excluded by the two main reviewers at the level 1 screening stage, confirmed all decisions to exclude and disagreed with only one reason for exclusion (0.56% error rate). We provide the full references of all included records in Appendix B.

2.3.1. Numerical analysis – description of records

General characteristics of included records

Table 2.4 summarizes the general characteristics of the 84 records included in this review. A more comprehensive summary of the 84 included records (i.e., completed charting spreadsheet) can viewed in the supporting information section of our published manuscript: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0171652#sec032. The majority of records were identified through the original academic database search (n = 51, 60.7%). Most records (n = 50) were categorized under the biomechanical efficacy theme and reported on published laboratory studies. There were 20 records within the clinical effectiveness theme, 12 within cost-effectiveness, and 17 within workplace safety, with most records from these 3 themes describing research in clinical settings (e.g., acute care and LTC). Thirty-nine percent of records were retrieved from other search strategies (n = 33; 17 from consultations with content experts, 8 from conference proceedings, 5 from searching reference lists of included records, 2 from post-baseline academic searches, 1 from target websites). The majority of the included records focused primarily on compliant flooring findings (n = 67; 79.8%), which we defined as records that had at least one study objective related to compliant flooring (for primary research) or records that strictly discussed compliant flooring as a fall-related injury prevention intervention (for secondary research or non-empirical evidence).

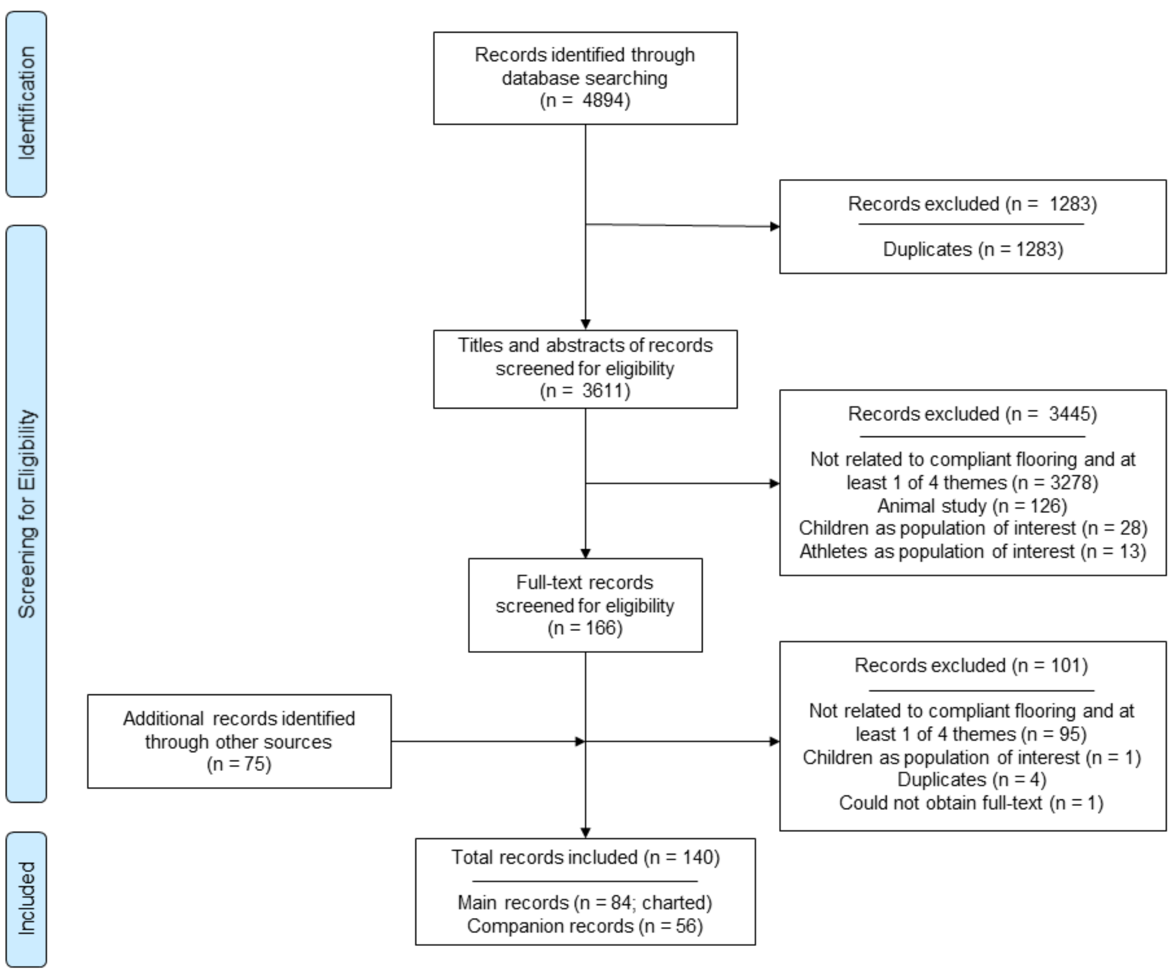

Figure 2.1 Study flow diagram
Diagram adapted from PRISMA [127]. Records identified from other sources were obtained from content experts, abstract/conference proceedings, clinical trial registries, reference lists, targeted websites, table of contents of Age Ageing, and post-baseline academic searches.

Table 2.4 Description of included records

Coding Category	Characteristic	Frequency	Percentage
Category (n = 84)	Academic Literature	53	63.1
	Grey Literature	31	36.9
Theme (n = 84)	Biomechanical efficacy	50	59.5
	Clinical effectiveness	20	23.8
	Workplace safety	17	20.2
	Cost-effectiveness	12	14.3
Primarily focused on compliant flooring findings (n = 84)	--	67	79.8
Source of literature (n = 84)	Record from original academic search	51	60.7
	MEDLINE	*21*	*41.2*
	Web of Science	*11*	*21.6*
	CINAHL	*9*	*17.6*
	AgeLine	*7*	*13.7*
	Ergo-Abs	*1*	*2.0*
	Cochrane Database of Systematic Reviews	*1*	*2.0*
	SportDiscus	*1*	*2.0*
	Record from experts	17	20.2
	Record from conference	8	9.5
	Record from reference list	5	6.0
	Record from academic search post-baseline	2	2.4
	MEDLINE	*1*	*50.0*
	Web of Science	*1*	*50.0*
	Record from website	1	1.2
	Record from Proquest Thesis/Dissertation search	0	0.0
	Record from clinical trial registries	0	0.0
	Record from Age Ageing table of contents	0	0.0
Journal Category (n = 53)	Engineering, other	13	24.5
	Engineering, biomedical	10	18.9
	Geriatrics and gerontology	9	17.0
	Public, environmental, and occupational health	9	17.0
	Rehabilitation	6	11.3
	Nursing	4	7.5
	Orthopaedics	2	3.8

Non-English Record (n = 84)	--	1	1.2
Type of Record (n = 84)	Original article	49	58.3
	Conference abstract/proceeding	13	15.5
	Non-systematic review	6	7.1
	Report	5	6.0
	Thesis/dissertation	5	6.0
	Book/book chapter	2	2.4
	Editorial/opinion piece	2	2.4
	Periodical	1	1.2
	Clinical trial registration	1	1.2
Primary Study Design (n = 86)*	Controlled experiment	51	59.3
	Simulation study	11	12.8
	Non-systematic review	7	8.1
	Randomized control trial	3	3.5
	Opinion piece	2	2.3
	Retrospective cohort study	2	2.3
	Non-randomized controlled trial	2	2.3
	Report	1	1.2
	Survey	1	1.2
	Longitudinal comparative cohort study	1	1.2
	Qualitative Methods	1	1.2
	Prospective cohort study	1	1.2
	Longitudinal observational study	1	1.2
	Not applicable	2	2.3
Country of origin (n = 85)†	United States	34	40.0
	Canada	18	21.2
	United Kingdom	14	16.5
	Sweden	6	7.1
	New Zealand	5	5.9
	Japan	3	3.5
	Australia	3	3.5
	Brazil	1	1.2
	Netherlands	1	1.2
Setting (n = 84)	Laboratory	15	17.9
	Hospital/acute care	14	16.7
	Long-term care/nursing home	10	11.9
	Community	2	2.4
	Other‡	4	4.8
	Not reported/no setting	39	46.4

Population (n = 96)	Older adults (65+ years)	34	35.4
	Adults (18-64 years)	24	25.0
	Special populations	10	10.4
	Not reported	5	5.2
	Not applicable	23	24.0
Decade of Publication (n = 84)	1980 - 1989	3	3.6
	1990 - 1999	16	19.0
	2000 - 2009	26	31.0
	2010 - 2016	39	46.4

Note. Numbers may be higher than 84 records as each record can span multiple categories.
* 3 studies used both controlled experiment and modelling study designs.
† 1 study took place in nursing homes across the United Kingdom and Australia.
‡ Other study settings include assisted living (1), hospice (1), industrial setting (1), and conference center (1).

Of the 84 included records, 53 (63.1%) were considered academic and 31 (36.9%) were grey literature. Records originated from several countries, but the majority of records were from the United States (n = 34, 40.0%), Canada (n = 18, 21.2%), and the United Kingdom (n = 14, 16.5%). Academic records came from a variety of disciplines, with most journal articles originating from engineering (43.4%), geriatrics and gerontology (17.0%), and public, environmental, and occupational health (17.0%). A majority of these academic records were original research studies (n = 49, 58.3%) that were controlled experiments. Grey literature records comprised several types of records, including conference proceedings (29.0%), theses/dissertations (16.1%), and abstracts (12.9%).

All included records were published between 1981 and May 2016, and the number of records produced per year increased steadily over time (e.g., 56.0% [47/84] of all included records were published within the last 10 years). In the first two decades of compliant flooring research (1980s and 1990s), records focused primarily on carpet and how its relative softness could prevent injury, with the exception of one record [129]. In the following decade (2000-2009), researchers investigated various combinations of carpets and underlays to create even more cushioned impact surfaces. Research on purpose-designed novel compliant flooring (NCFs; i.e., flooring systems designed specifically with the intention of preventing fall-related injuries) became more prominent in the late 2000s through present day.

Flooring systems examined

Across all records, we identified 183 unique flooring conditions that had been studied, which we classified into 4 categories: thick vinyl (> 5 mm; n = 2 records), carpet with no underlay (e.g., commercial grade, residential grade, carpet tile; n = 32), NCFs with no underlay or overlay (e.g., SmartCells, Sorbashock, Kradal; n = 27) and combination floorings (i.e., flooring with an overlay and an underlay which were not purchased as one single flooring type, e.g., SmartCells underlay adhered to a vinyl overlay; n = 27). Of the 32 records examining carpet conditions, 13 studied thin carpets (<0.50 cm), 8 studied thick carpets (>0.50 cm), 3 studied carpet tiles, and 11 did not report carpet thickness. Of the 27 records examining combination floorings, 15 examined vinyl with compliant flooring underlay, 3 examined vinyl with padded underlays (e.g., foam, rubber), 15 examined carpet with padded underlay, 7 examined carpet with compliant flooring underlay, and 2 examined carpet with wood underlay. Comparators or control floors studied commonly included a rigid force plate, concrete, thin vinyl, and 'standard flooring.'

Consistency of terms

There were 29 unique terms used to describe NCF, which we reduced to 13 terms by allocating the stem words as minor variations (**Table 2.5**). The three most prevalent terms stemmed from derivatives of compliant flooring, safety flooring, and soft flooring.

Table 2.5 Terms used to describe novel compliant flooring

Term	Number of Records using Term	Percentage of records
Compliant flooring (5 minor variations*)	19	24.7
Safety flooring (3 minor variations*)	11	14.3
Soft flooring (6 minor variations*)	10	13.0
Impact absorbing flooring (2 minor variations*)	8	10.4
Energy absorbing flooring (3 minor variations*)	6	7.8
Shock-absorbing flooring	5	6.5
Low-impact flooring	5	6.5
Dual-stiffness flooring (2 minor variations*)	4	5.2
Low stiffness flooring	3	3.9
Absorptive surfaces (2 minor variations*)	3	3.9
Cushioned flooring	2	2.6
Rubberized flooring	1	1.3
New flooring system	1	1.3

Note. * Variations of each flooring term were as follows: Compliant flooring - Compliant floor(ing), Compliant surface(s), more compliant floors and subfloors; Novel compliant flooring, novel compliant flooring systems; Safety flooring - Safety floor(ing/s), Novel safety flooring systems, Safety flooring systems; Soft flooring - Soft(er) floor(ing/s), Soft-surface flooring, Softer surface(s), Softer floor surfaces, Softer floor types, Softer ground; Impact absorbing flooring - Impact absorbent flooring, Impact-absorbing flooring; Energy absorbing flooring - Energy absorbing flooring, Energy-absorbing materials, Energy absorbent flooring; Dual-stiffness flooring – Dual-stiffness floor(ing), Dual stiffness flooring, Dually stiff floor; Absorptive Surfaces – Absorptive surfaces, Absorbent flooring.

2.3.2. Narrative analysis – biomechanical efficacy (n = 50)

What evidence exists from experiments conducted in a controlled, laboratory environment about impact force attenuation or energy absorption during real or simulated falls onto compliant flooring systems?

Twenty records provided details about the ability of compliant flooring to absorb energy and attenuate force in the event of an impact [64,130–147]. Evidence of meaningful amounts of force attenuation and energy absorption exists specifically at the hip (n = 16) [64,130–143,148], head (n = 2) [145,146], and hand [64], with most records having been conducted in a laboratory setting using artificial surrogates (e.g., headform, surrogate pelvis; n = 13, 65%), versus human subjects.

For hip impacts, carpet without an underlay did not provide enough force attenuation to suggest it would be protective against injury to the hip [141,142,149]. Carpet with the addition of an underlay (e.g., 12 mm PVC foam) provides better force attenuation than carpet alone [64,131,138,142,143,148], and has been shown to reduce forces below the threshold for hip fracture (2-2.5 kN) [142,143]. Compared to standard flooring, carpet with underlay has been shown to provide 7 – 23% force attenuation at the hip [64,135].

Overall, NCFs have been shown to attenuate hip impact forces by 16.4 to 51.2% [130,134,136] compared to a rigid surface and can reduce impact forces below the average fracture force of older cadaver femora [139]. NCFs can reduce energy absorption at the hip even more than carpet with underlay [133,137]; all NCFs tested by Glinka and colleagues (Kradal, 1.27 cm; Kradal, 2.54 cm; SmartCell, 2.54 cm with or without carpet tile overlay) absorbed 3.2 to 5.4 fold more energy than commercial carpet with foam underlay (0.96 cm) [137]. SmartCell (2.54 cm) and SofTile (10.00 cm) NCFs, were also shown to provide greater force attenuation as impact velocity increased from 2 m/s to 4 m/s (SmartCell from 17.3-33.7%; SofTile from 44.9-51.2%), suggesting these flooring systems have greater protective capacity as impact severity increases [130].

For head impacts, NCF (SmartCell, 2.54 cm with and without vinyl overlay; SofTile, 5.00 cm with and without vinyl overlay; Kradal, 1.2 cm; Kradal, 2.40 cm) provides more protection than commercial carpet [146]. Impact forces were 20-80% lower, and the authors reported that the risk of a moderate head injury (based on Head Injury Criteria) is 5-25% for a head impact on NCF versus an 80-90% risk on carpet. Additionally, Paka [145] found that the benefits of force attenuation at the head translated into lower coup and contrecoup pressures and reduced shear stresses on the brain when falling on rubber versus wood.

Maki and colleagues [64] examined hand impacts in addition to hip impacts. Contrary to other impact sites, no differences were found between carpet and standard flooring for hand impacts.

What evidence exists from experiments conducted in a controlled, laboratory environment about balance, gait and mobility performance, and/or assistive device use on compliant flooring systems?

Thirty records considered how different types of compliant flooring might affect standing or walking balance [88,129,130,132,136,137,150–173]. Human participants comprised various age groups and categories, including adults (18-64 years, n = 9), older adults (65+ years, n = 16), and special populations (n = 4), such as Parkinson's Disease and stroke patients; 2 records did not use human participants (simulations only). Forty-eight percent tested a type of NCF (n = 13), 41% examined carpet (n = 11), and 11% looked at both carpet and NCF (n = 3).

Overall, participants were able to maintain static and dynamic balance on carpet [153,154,161,162,173] and NCFs [129,130,136,151,152,160,163,168,170,172]. One exception was for NCFs; subjects' anteroposterior sway range during quiet stance was higher [129] and peak centre of mass displacement was larger [170] relative to rigid flooring, indicating decreased stability. Many different measures were used to test balance. For example, postural angles were measured to look at body motion [152,161], and root mean square of postural sway [129,130,136,151,163], centre of mass/pressure margin of safety [146,163,173], and mean velocity of postural sway [130,136,163,165] were measured to determine level of postural stability.

Of the 14 records that looked at gait/mobility measures, 6 did not report any significant changes when walking over carpet or NCF compared to standard flooring [132,150,156,160,164,166], 5 reported beneficial attributes of carpet or NCF on gait performance [130,155,157,167,171], and 3 reported negative attributes of carpet or NCF on gait performance [88,158,169]. Similar to the balance studies, there were a variety of measures used to measure gait and mobility performance including: gait speed [150,169,171], step length [167,171], toe clearance [157,167], Timed Up-and-Go time [164], and locomotive energy cost/loss [156,158]. A few records suggested some carpets (versus standard flooring) were favourable for walking when gait speed [171], step length [171], walking pattern [155], and obstacle avoidance [157] were considered. Willmott suggested walking on carpet was more efficient than walking on vinyl based on observed increases in gait speed [171]; however, Stephens et al. [169] found carpet resulted in slower walking speed versus parquetry flooring. Walking on rubber flooring (thickness not reported) also resulted in an increase in energy losses, but <10% in maximal angle deviations during unperturbed gait [158]. Similar to the potential benefits of carpet on gait, SmartCell NCF was suggested to be more stable for participants than vinyl; no differences were found in 6 of 8 tested gait parameters [167]. In addition, no differences were found between SmartCell (2.54 cm), SofTile (10.00 cm) and vinyl floors for Timed Up-and-Go times [130]. Only Hanger et al. [88] suggested negative effects on gait from a low impact flooring, specifically for Parkinson's patients. Balance and gait will ultimately be impaired by large reductions in ground stiffness; however, the evidence suggests that most NCFs are stiffer than the threshold required causing significant impairment. Overall, the available evidence suggests that the compliance of these flooring systems have limited effects on gait and mobility, except in those who have neurological dysfunction.

Eight records considered mobility aide use, specifically wheelchairs with carpet (n = 7) [138,144,156,174–177] and walkers with NCF (n = 2) [144,164]. The effect of compliant flooring on propelling a wheelchair largely depended on the specific floor type, but there is evidence to suggest compliant flooring may not affect the use of walkers. Van Derwoude [177] found high-pile carpet increases rolling resistance and average work per meter [174] required for individuals using wheelchairs to self-propel compared with standard flooring (e.g., tile, vinyl, and plywood). Low-pile carpet increased the energy cost and cardiopulmonary response for wheelchair locomotion when travelling from tile to carpet [156]. However, Mercer et al. [176] did not observe any differences in manual wheelchair propulsion when comparing carpet with tile, but acknowledged that the carpet pile may have been too thin to provide enough resistance to affect propulsion. In addition, Koontz et al. [175] found that high-pile carpet, low-pile carpet, and the control surface (concrete) required less torque than interlocking pavers and a ramp condition. With NCF, Hales et al. [138] did not observe any differences in manual wheelchair propulsion when comparing proprietary compliant flooring to tile. Okan et al. [164] found that compared with standard flooring, NCF affected Timed-Up-and-Go times (a measure of mobility) in older adults who used walkers, but had no effect on self-ambulating older adults [164]. Furthermore, balance was not affected by the NCF for any participants (with or without walker use) [164]. Finally, a trial examining Powerbond compliant flooring by Yarme [144] concluded that the flooring did not affect wheelchair and walker use for older adults residing in LTC, after 1 year of monitoring.

2.3.3. Narrative analysis – clinical effectiveness (n = 20)

What evidence exists from research involving human participants and measurement of how compliant flooring affects fall-related injuries?

Fourteen records examined whether compliant flooring would reduce the incidence of fall-related injuries. Eleven records reported some evidence of injury reduction in areas with compliant flooring versus standard flooring [88,131,144,147,178–184], 2 records reported no significant difference in the incidence of fall-related injuries [185,186], and 1 record described a protocol for an ongoing randomized controlled trial [187].

Of the 11 records that reported indications of injury reduction, only 3 records provided statistical evidence that compliant flooring reduced the incidence of fall-related injuries. A 4-year retrospective cohort study in acute care found 29% fewer injuries in older patients (n = 213) on carpet (17% of falls resulted in injuries) versus vinyl (46%; unspecified type) [178]. Gustavsson and colleagues [179] conducted a 2.5 year quasi experimental, non-randomized controlled trial to evaluate the effect of compliant flooring on fall-related injury risk for women (n = 57) in a Swedish LTC setting by comparing compliant flooring (Kradal, 1.20 cm) to standard flooring (vinyl, linoleum, ceramic tile, thickness not specified). The injury/fall rate was 30.3% on standard flooring and 16.9% on compliant flooring [179]. After adjusting for body-mass index, compliant flooring significantly reduced the relative risk of injury in the event of a fall by 59% (RR 0.41; 95% CI 0.20 to 0.80) compared to standard flooring [179]. A 2-year prospective cohort study in LTC aimed to evaluate whether floor properties had a significant effect on the risk of a fracture occurring in a fall (sample size not reported). By examining different flooring types (uncarpeted concrete, carpeted concrete, uncarpeted wood, carpeted wood– thickness not specified for any floors), the authors estimated that the risk of breaking a hip in a fall would be reduced by 80% if carpet was laid on uncarpeted wooden floors (OR 1.78; 95% CI 1.33 to 2.35) [131]. Carpet with a concrete underlay was not associated with a significantly lower risk of hip fracture following a fall. In addition, 7 grey literature records and 1 non-systematic review provided general statements that compliant flooring could reduce the incidence of injuries (sample size not reported), but did not provide sufficient details to conclude whether this evidence was from measured, experimental observation (i.e., no quantitative results were presented nor was any statistical significance testing performed) [88,144,147,180–184].

Among the 2 records that reported no significant difference in the incidence of fall-related injuries, Warren and Hanger [186] conducted a non-randomized, longitudinal observational study (n = 4641) in acute care to examine fracture rates on carpet (loop-pile carpet tile, 0.50 cm) versus thick vinyl (unspecified type, 0.50 cm). 15 fractures occurred on carpet (0.75 fractures per 100 falls) compared to a 11 that occurred on vinyl (1.33 per 100 falls); the difference was not statistically different [186]. In an unblinded, pilot cluster randomized controlled trial conducted by Drahota and colleagues, geriatric wards at eight hospitals were allocated to compliant (Tarkett Omnisports EXCEL, 0.83 cm) or standard (control, unspecified type) flooring (Helping Injury Prevention in Hospitalised Older People (HIP-HOP) Flooring Study; n = 442) [185]. During one year of outcome monitoring, 23% of falls (8 of 35) were injurious in intervention wards compared to 42% of falls (14 of 33) in control wards. Though this difference was not statistically significant (IRR = 0.58, 95% CI 81% reduction to 91% increase) and was underpowered to detect a change, the authors concluded that shock-absorbing flooring could potentially reduce injury rates by 42%. No moderate or major severity injuries occurred in intervention wards, while six occurred in control wards [185].

The protocol record describes the Flooring for Injury Prevention (FLIP) Study, which is a 4-year, parallel group, randomized controlled superiority trial [187]. Outcome ascertainment began September 2013. One-hundred and fifty resident rooms at one LTC site were randomized to receive either NCF (SmartCells, 2.54 cm; 74 rooms) or standard flooring (plywood, 2.54 cm; 76 rooms), each with identical vinyl (0.20 cm) floor covering. The primary outcome is to determine whether NCF reduces serious fall-related injuries relative to control flooring, defined as any impact-related injury due to a fall in a study (resident) room that results in Emergency Department visit or hospital admission. The trial is also monitoring the incidence of minor fall-related injuries, fractures and falls, as well as the number of fallers, and health care utilization and costs for serious fall-related injuries [187].

In addition, two records discussed severity of fall-related injuries, though neither record performed statistical testing on the reported frequency counts [179,188]. A 2.5-year retrospective study at a LTC site found there was a non-significant trend for fewer bruises (66%) and abrasions (56%) from falls on compliant flooring (SmartCells, 2.54 cm with vinyl overlay) than falls on standard flooring; however, there was a higher prevalence of redness (100%) and cuts (43%) on compliant flooring [188]. While two falls on standard flooring resulted in fracture, no falls on compliant flooring resulted in fracture [188]. Though Gustavsson and colleagues' study [179] reported a significant 59% reduction in risk for fall-related injury for falls that occurred on compliant flooring (Kradal, 1.25 cm), they also acknowledged that 80% of fall-related injuries were of minor severity (e.g., distinct pain, bruising, swelling). While there was a significant reduction in minor and moderate injuries, there was insufficient statistical power to test the effect of compliant flooring on less common, more serious fall-related injuries [179].

What evidence exists from research involving human participants and measurement of how compliant flooring affects falls?

Three records performed statistical testing to examine whether compliant flooring increases the risk of falling in older adults [131,185,186]. Two records, which described studies in acute care, did not find evidence that compliant flooring alters rates of falling [185,186]. Firstly, Warren et al. [186] did not find a significant difference in fall rates following a change from carpet tile (0.50 cm) to vinyl (0.50 cm). There were 854 falls on carpet in the 12 months prior to the flooring change and 878 falls on vinyl the 12 months after (19.5 and 19.6 falls/1000 bed days, respectively) [186]. Further, in the Drahota et al. study [185], the incident rate for falls was only slightly higher in the intervention group (n = 35 falls; IR = 7.81 falls per 1,000 OBD) compared with control (n = 33 falls; IR = 7.17 falls per 1,000 OBD), since there were more recurrent fallers in the control group. The (uncertain) estimated effect of the intervention flooring on falls was an increase of ~7% relative to control (adjusted IRR = 1.07, 95% CI 0.64 to 1.81, k = 0.226), which they found to be larger when examining hazard ratios (adjusted HR = 1.13, 95% CI 0.83 to 1.55) [185]. Finally, the Simpson et al. study [131] (the same prospective cohort study that found an 80% hip fracture risk reduction if carpet was laid on uncarpeted wooden flooring) found an increase in the rate of falling on carpet (RR 2.74 – 4.30), though the authors mentioned that these results were likely confounded by differences in exposure time.

2.3.4. Narrative analysis – cost effectiveness (n = 12)

What evidence exists related to the costs of compliant flooring systems relative to their effects on fall and fall-related injury health care costs?

Six records discussed the direct cost [98,130,189–191] or incremental cost of purchasing and installing NCFs relative to standard flooring [98,130,189,191,192] (**Table 2.6**). Costs have been reported for the following brands: SmartCell, SoftTile, Tarkett Omnisport EXCEL, Kradal, and Penn State Flooring. Acknowledging that the pricing of compliant flooring was reported using different currencies and over multiple years, we converted all costs to reflect 2015 US dollars [193]. The average absolute direct cost of purchasing and installing a NCF system was $236.61 US dollars per square meter (range: $100.54 – $538.20 per square meter) [98,130,189–191]. In addition, the average incremental cost of purchasing and installing a NCF system was $196.30 US dollars per square meter (range: $50.27 – $511.29). Two records described but did not quantify that carpet was more expensive to install, maintain and replace compared to vinyl [138,147].

Table 2.6 Costs of novel compliant flooring systems

Citation	Verbatim Cost of Compliant Flooring	Converted Cost (2015 USD/m²)	Brand of Compliant Flooring	Verbatim Incremental Cost†	Converted Incremental Cost (2015 USD/m²)
Laing (2009)	161 CAD/m²	$121.14	SmartCell or SofTile	134 CAD	$100.83
Lange (2012)	1600 SEK/m²	$182.34	Not reported	1200 SEK	$136.75
Latimer (2013)	164 GBP/m²	$240.82	Tarkett Omnisport EXCEL	Not reported	N/A
Njogu (2008)	150 NZD/m²	$100.54	Not reported	75 NZD	$50.27
Ryen (2015)	Not reported	Not applicable	Kradal	1600 SEK	$182.34
Zacker (1998)	50 USD/ft²	$538.20	Penn State Flooring with vinyl overlay	47.50 USD	$511.29

Note. *Acknowledging that the pricing of flooring came from many years, if this was based from 2015 prices, this table would reflect the 2015 values in US Dollars. Source. https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates

† Incremental cost = cost of compliant flooring - cost of traditional flooring

‡ /m2 = per square meter; /ft2 = per square foot; CAD = Canadian Dollar; SEK = Swedish Krona; GBP = British Pound; NZD = New Zealand Dollar; USD = US Dollar

Six records provided cost-effectiveness or pay-off estimates for compliant flooring [98,130,138,189–192]. The 2 most extensive studies of cost-effectiveness, which were published in peer-reviewed journals, examined Tarkett Omnisport EXCEL (0.83 cm) [190] and Penn State Flooring (2.50 cm + vinyl overlay) [191]. As part of the HIP-HOP Flooring Study [185], Latimer and colleagues [190] reported model estimate costs and quality adjusted life-years (QALYs) of $57 415.57 USD and 0.425 per patient in the control group and $56 177.68 USD and 0.419 in the intervention group. Latimer et al. [190] concluded that Tarkett Omnisport EXCEL flooring is associated with a cost reduction of $1 237.89 per patient, a QALY loss of 0.006 and an incremental cost-effectiveness ratio (ICER) of $198 095.45 USD. The authors suggested compliant flooring is cost-effective as the cost savings per QALY lost are >$29 368.58 USD while acknowledging their primary analysis results were extremely sensitive to the risk of falling. Thus Latimer and colleagues performed a secondary analysis that assumed an equal risk of falls, but lower proportion of severe falls in the intervention group (as suggested by the associated clinical trial [185]), to find that the intervention floor was expected to provide cost savings and QALY gains, making it a dominant strategy. Another cost-effectiveness analysis by Zacker and Shea [191], estimated a payback period of 10.5 years if only direct costs avoided were evaluated (cost-benefit ratio (CBR) = 0.61) and approximately 11 months when direct and indirect costs were included (CBR = 0.06). Zacker and Shea [191] derived these numbers using the following assumptions: five falls per year for eight patients, the direct cost of a hip fracture being $18 000 USD and the expected costs of falls with conventional flooring as $14 400 USD per year versus $7 200 with safety flooring. For the best case, the CBR was very favourable and the cost-effectiveness ratio (CER) was less than $0 per life-year saved. This result was robust in the worst-case scenario when considering indirect costs. However, when only direct costs were considered in this case, the CBR was >1 and no longer favourable. Zacker and Shea [191] concluded that the flooring system could be cost saving given the expected reduction in hip fractures.

2.3.5. Narrative analysis – workplace safety (n = 17)

What evidence exists from research about the effects of compliant flooring systems on musculoskeletal health and fatigue of health care workers as a direct result of differences in flooring compliance?

Of the 17 articles that examined workplace safety of compliant flooring, five original research studies [88,147,194–196] found benefits of compliant flooring for health care workers. Survey results from 2 records suggested that compliant flooring (unspecified type) provides more comfort for acute care staff [88,164] (sample sizes: not reported; n = 9) than standard (unspecified type) flooring. In addition, a 42-week longitudinal comparative cohort study found that carpet (tufted-level loop carpet tile, thickness not reported) and compliant flooring (resilient rubber, 0.30 cm) reduced perceptions of fatigue due to underfoot impact in acute care staff compared to control (Terrazzo) flooring [195] (n = 102). A non-randomized controlled trial of 153 LTC staff observed the effects of installing a thick vinyl (0.40 cm) compared to a thin vinyl (0.20 cm) [194]. After a 2-year follow-up, LTC staff reported decreased pain intensity score in their feet (mean difference -1.67, 95% CI – 2.70 to – 0.65) [194]. Finally, one record found that carpet increased the forces required for nurses and nursing students to push a medicine carts, but reduced the amount of force required to stop the cart compared to tile flooring [196].

Most (n = 16, 88.9%) of the workplace safety records reported some negative effects of compliant flooring on health care workers, including 14 original research studies [88,142,164,177,185,187,195–202] and two opinion pieces [203,204].

Focus group findings (sample size not reported) revealed that compliant flooring (Kradal, 1.20 cm) increased subjective ratings of leg fatigue for LTC nurses and difficulty when maneuvering equipment when compared to standard flooring (vinyl, linoleum, tile) [200]. In addition, six other records noted increased subjective ratings of perceived fatigue when maneuvering equipment, including beds [88,164,199,200,203,204], wheelchairs [164,200,204], stretchers [203,204], and floor-based lifts [88,164,199,200,205] over both carpet (n = 3 records) and NCF (n = 4 records) in acute and LTC settings.

Eight records revealed that carpet and NCFs increase the forces required to maneuver (push, pull, and/or turn) carts [196–198], beds/patient trolleys [201], wheelchairs [142,177], and floor-based lifts [201,202,205]. When considering recommended limits to safely maneuver equipment, 3 (of 6) records that examined carpet [198,202,205] and 2 (of 3) records that examined NCF [201,205] recorded values that were over the recommended limits, suggesting an increased risk for injury. Keeping the forces required to move equipment within recommended limits is essential to prevent injury, as indicated by one record which documented 5 adverse events from staff working on a NCF in a 16 month period, including 1 lower back muscle strain while moving a patient on a trolley (Tarkett Omnisport Excel, 0.83 cm) [185].

2.4. Discussion

This study is the first scoping review to synthesize the available evidence about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems that aim to prevent fall-related injuries. We followed the original Arksey and O'Malley framework [206] and published updates to it [123–126], and we searched both academic and grey literature. In addition, our Research Advisory Panel of knowledge users provided guidance on development of the research question, key definitions, interpretation of findings and gaps in the research, and dissemination of findings. This scoping review builds considerably on a 2010 report on compliant flooring by the Canadian Agency for Drugs and Technologies in Health [121].

Eighty-four records plus 56 companion records satisfied our inclusion criteria. Our included records comprised 183 unique flooring conditions, which we categorized into thick vinyl (> 5 mm), carpet, NCFs, and combination floorings, and 29 unique terms to describe NCFs. The majority of records were identified through our original academic database search (60.7%); however, 39.3% came from other approaches, emphasizing the importance of additional search strategies.

The primary finding of this review is that compliant flooring is a promising strategy for fall injury prevention from a biomechanical perspective, but more research is needed in clinical environments to determine if the established biomechanical efficacy translates into an injury prevention strategy that is clinically and cost-effective and that does not negatively influence safety in the workplace. Though preliminary evidence exists, there is a paucity of literature on these 3 themes (clinical effectiveness n = 20 studies, cost-effectiveness n = 12 studies, workplace safety n = 17 studies) compared to the biomechanical efficacy theme (n = 50 studies).

The biomechanical efficacy theme contained the largest number of records and examined the greatest number of compliant flooring systems. Laboratory evidence demonstrates compliant flooring reduces impact forces during simulated falls and has minimal effects on standing or walking balance for self-ambulating individuals. However, preliminary evidence suggests that balance and mobility performance may be impaired for users of assistive devices (e.g., wheelchairs). Despite the substantive biomechanical evidence, sample sizes of individual studies were generally small and testing protocols used surrogate hips, heads, hands or young adults as participants. Thus, results may or may not be transferrable to target users, including older adults at risk of falling. Overall, results from biomechanical testing of compliant flooring provided strong enough evidence that 8 records suggested a clinical trial is warranted to test clinical effectiveness in a real-world setting[64,130,133,136,138,142,146,172].

A small number of clinical studies have examined the ability of compliant flooring to prevent fall-related injuries in acute and LTC settings. Research performed in clinical settings provided some preliminary, but not conclusive, evidence of compliant flooring reducing the incidence and severity of fall-related injuries in such settings, but also indicated that compliant flooring may increase the risk of falling. The number of fall-related injuries observed within individual studies have been small, precluding definitive conclusions. In particular, no randomized controlled trial has been sufficiently powered to test the effectiveness of compliant flooring for reducing fall-related injuries. However, the FLIP Study is an ongoing randomized controlled trial in LTC, and it has been powered for the primary outcome of serious fall-related injury [187].

Overall, compliant flooring systems cost more than standard flooring. The average reported 2015 cost of NCF was $236.61 US dollars per square meter, and the average 2015 incremental cost relative to standard flooring was $196.30 US dollars per square meter. The records examining cost-effectiveness provide preliminary indications that compliant flooring may be a cost-effective strategy for health care systems with older adults at risk for falling. Most cost-effectiveness analyses were based on the potential cost savings from hip fracture prevention only, which may underestimate the cost-effectiveness of compliant flooring.

From the current body of evidence, compliant flooring may pose health and safety risks for health care workers. Although some evidence found compliant flooring increased comfort and reduced the perception of fatigue due to underfoot impact among health care workers, more evidence suggested that compliant flooring makes it more difficult for workers to perform standard tasks, including maneuvering equipment (e.g., floor-based lifts, wheelchairs, beds/patient trolleys), compared to standard flooring.

2.4.1. Gaps in the literature and recommendations for future research

In conducting this review, we identified a number of gaps in the available evidence that suggest important avenues for future research. These gaps were identified by extracting the suggestions for future research from the included records and were later reviewed by our Research Advisory Panel. First, the highest priority is for additional studies to investigate the clinical effectiveness studies of compliant flooring. Such studies require rigorous methodologies, such as blinded, randomized controlled trials with sufficient sample sizes and follow-up periods to provide adequately powered and conclusive results. To help facilitate future cost-effectiveness studies, future clinical trials should consider including economic evaluations. Additionally, since so many falls go unwitnessed, researchers should consider video surveillance of study areas to increase accuracy in reporting falls and fall-related injuries [207], though privacy issues will need to be addressed in bedroom and bathroom areas. When study sites have multiple types of flooring, it would be beneficial to track participant exposure time to compliant flooring to yield more accurate estimates of the effects of compliant flooring. Future studies should also consider evaluating whether compliant flooring results in an increased risk for falling and determine if specific brands of compliant flooring have more or less of an effect on falling than others. No clinical studies in this review discussed where to prioritize the installation of compliant flooring within a LTC site (i.e., coverage), yet this is a practical issue that knowledge users may encounter, especially when under financial constraints.

Second, most cost-effectiveness studies have only included hip fracture costs; thus, there is value in expanding to include other injuries (e.g., all fractures, head injuries, soft-tissue injuries) in future research. Since there were relatively few records examining cost-effectiveness, future research should examine different types of compliant flooring to determine if certain brands of compliant flooring are more cost-effective than others. In addition, although some records mentioned the cost differences between standard and compliant flooring systems, there was no mention of how costs would vary if compliant flooring was installed during a building retrofit installation versus a new build. Thus, researchers should consider costing out the differences between these two scenarios to better inform knowledge users.

Third, the number of records representing the workplace theme is relatively small and, in general, conclusions were derived from small sample sizes. Despite several records acknowledging that compliant flooring increases the effort or forces required for participants to use medical equipment, only a few records tested a proposed solution (i.e., modifications to wheel characteristics, using motorized floor-based and ceiling-mounted patient lift systems instead of conventional floor-based lifts [197,200,202,205]). Future workplace safety studies should work to identify and examine additional potential solutions to the previously identified concerns of maneuvering equipment over compliant flooring. Future study protocols should also reflect tasks and situations that are common in the workplace, such as measuring the force requirements to move equipment in confined spaces [202,205], testing a variety of health care worker populations, including novice and aging populations [196,199,200,203], randomizing the conditions being compared, and blinding the flooring systems that are being evaluated (when possible) [164].

Finally, despite the promising existing biomechanical evidence, future biomechanical studies should consider examining the effects of compliant flooring on dynamic balance and more complex mobility tasks (e.g., gait performance while conducting activities of daily living). It is especially important to test these outcomes, and other biomechanical measures, using the population of interest (i.e., frail older adults) when ethically appropriate and logistically possible, as there is a dearth of biomechanical studies with older adults who are at high-risk of falling or having a history of falling. Most biomechanical records with human subjects involved relatively young adults (18 – 64 years) or healthy, community-dwelling older adults (65+ years) to draw conclusions about how compliant flooring may affect older adults in general. For example, only 19.6% (n = 10) of the records in this theme involved high-risk older adults who were not living independently [65,71,88,91,144,160,163,208–210], and only 13.7% (n = 7) examined special populations [176,208,211–213] that are common in high-risk environments (i.e., LTC), such as individuals with Parkinson's disease and individuals who are dependent on an assistive device. Understanding the effects of compliant flooring on various populations will help to assess feasibility of installing compliant flooring in high-risk environments, including acute care and LTC.

2.4.2. Limitations

Though our scoping review followed a standardized approach and used a Research Advisory Panel as consultants throughout the research process, our review has certain limitations. The review provided breadth but not depth about the topic, consistent with scoping review methodology [206]. Additionally, we did not assess the risk of bias nor use a rating of quality of evidence, and therefore, we cannot grade recommendations for practice [214]. This is also consistent with scoping review methodology [214]. An additional limitation is that the grey literature search was limited to records published in the English language from 1990 or later, which is when the first academic records on the biomechanical efficacy of compliant flooring were published. Finally, the results reported in the records we examined were based on the specific flooring types used in each study, and therefore, may not be generalizable to other floors.

2.4.3. Conclusions

In conclusion, compliant flooring is a promising strategy for fall injury prevention based on existing literature that has examined biomechanical efficacy. Additional research is required, however, to determine if compliant flooring is clinically and cost-effective without negatively influencing the safety in the workplace. Future research should prioritize conducting randomized controlled trials to determine if compliant flooring is clinically efficacious.

Chapter 3. External Hand Forces Exerted by Long-Term Care Staff to Push Floor-Based Lifts: Effects of Flooring System and Resident Weight

3.1. Introduction

Falls are the leading cause of injury-related death and unintentional injury for older adults [3,21,22], including 90% of hip and wrist fractures [36,37,215] and 80% of traumatic brain injuries [33,34]. Falls and the injuries they cause in older adults cost $3 billion annually in Canada [1]. The long-term care (LTC) setting is a particularly high-risk environment for falls and fall-related injuries. Approximately 60% of LTC residents fall at least once per year, and 30% of falls in LTC cause injury, rates that are 2 to 3 times higher than for community-dwelling older adults [15,16]. LTC residents are 10 times more susceptible to sustaining a hip fracture [16,17,45] and experience higher mortality rates after a hip fracture [46–49]. Thus, there is a critical demand for effective intervention strategies to reduce the incidence and severity of fall-related injuries in LTC [71].

Novel compliant flooring (NCF) is a promising passive intervention strategy for reducing the incidence and severity of fall-related injuries in LTC [94,95,216]. Although compliant flooring is available in different forms (e.g., portable fall mats), NCF is commonly engineered as a subfloor underneath vinyl or carpet overlays, and is installed flush with the walls of a particular space. Laboratory studies have demonstrated that NCF reduces impact forces applied to the hip during simulated sideways falls by up to 35% [62,82] and to the head during simulated backwards falls by up to 60% [61], with minimal effects on balance and mobility [61,62,66,68,71]. Preliminary studies in acute [86,88,93] and LTC [94,95] settings suggest that falls on NCF appear to result in fewer fall-related injuries, including fractures, contusions, and abrasions. To be a feasible intervention in LTC, NCF must decrease the risk of fall-related injuries for residents without increasing the risk of musculoskeletal injury (MSI) for staff when performing regular job duties, as health care workers in LTC are already at especially high risk of suffering work-related MSI [217–220].

Due to its low stiffness and susceptibility to deform under load [82], NCF may increase rolling resistance versus standard flooring (e.g., concrete). Accordingly, there is concern that maneuvering wheeled equipment on NCF could expose staff to potentially injurious forces

[86,88,93], which would pose an important barrier to the uptake of NCF in LTC. Previous research has demonstrated that the floor surface influences the amount of rolling resistance and in turn affects the forces required to push wheeled equipment. For instance, Marras, Knapik, and Ferguson [221] found that maneuvering floor-based lifts on carpet, as compared to more rigid flooring, generally induced greater levels of anterior/posterior shear forces on the spine. However, there has been very limited research to quantify the external forces required to maneuver wheeled equipment on NCF. To our knowledge, only one gray literature report has been published, which showed that a single type of NCF (8.3-mm vinyl Tarkett Omnisports EXCEL) increased initial and sustained forces for a single operator to perform pushing and pulling tasks, especially when transporting heavy patient trolleys and beds [92]. However, between-operator differences in anthropometric characteristics and movement techniques impact measured forces [92], so studies of larger sample size are needed. Furthermore, the influence of NCF on external forces should be influenced by the amount of surface deformation and therefore may depend on resident weight. Over 50% of LTC residents are overweight or obese upon admission [222], so it is important to evaluate NCF during the transport of heavier residents. Moreover, approximately 75% of falls in LTC occur in resident bedrooms and bathrooms [223], so these are logical areas for installation of NCF. Within resident bedrooms and bathrooms, floor-based lifts are commonly used by care staff to assist with transferring residents who are unable to bear their full weight, but are capable of some self-generated mobility [224]; therefore, it is imperative to evaluate the forces required to maneuver floor-based lifts over NCF.

Not all types of lift systems are equally advantageous in minimizing overexertion and subsequent risk of work-related MSI. Compared to manual transferring, floor-based lifts and, to a greater extent, overhead or ceiling-mounted lifts reduce the biomechanical demands imposed on the user and, consequently, risk of work-related MSI [219,221,225–232]. As the operation of overhead or ceiling-mounted lifts is unaffected by properties of the ground surface, these represent an obvious technology to be used in locations which have NCF or other floors of increased rolling resistance (e.g., carpet). However, overhead lifts are not always a feasible solution due to lack of coverage within a LTC site or lack of uptake (e.g., inability to install in older LTC sites). To address this issue, a lift manufacturer developed a novel, motor-driven, floor-based lift to assist with resident transferring. A strain gauge load cell embedded within the handlebar of the motor-driven lift detects the magnitude and direction of force applied by the user, and drives an electric wheel to provide powered assistance. However, no studies have been published examining the ability of this motor-driven lift to reduce external hand forces during pushing.

Accordingly, the objectives of this study were to (a) determine the effects of flooring system (concrete+vinyl; compliant+vinyl; concrete+carpet; compliant+carpet) and resident weight (average, 90th percentile) on (i) the external hand forces required for LTC direct-care staff to push floor-based lifts and (ii) subjective ratings of pushing difficulty, and to determine if these effects are modified by lift type; and (b) compare forces from each experimental condition to recommended limits for tolerable pushing. We hypothesized that: (a) both push forces and subjective ratings would be higher on NCF than on standard flooring when using the conventional lift but not the motor-driven lift, (b) both push forces and subjective ratings would be higher when pushing the 90th percentile compared to average resident weight when using the conventional lift but not the motor-driven lift, (c) push forces would remain below tolerance limits for all experimental conditions involving the motor-driven lift, and (d) push forces when using the conventional lift would exceed tolerance limits for at least one flooring condition.

3.2. Methods

3.2.1. Participant eligibility criteria

We recruited front-line staff from one LTC site in New Westminster, British Columbia. LTC refers to sites for older adults where personal and nursing care is provided on a 24-hour basis (e.g., nursing homes, residential care facilities; [12]). To be eligible to participate care staff must: (i) be able to speak, read, and understand English fluently; (ii) be 19 years of age or older; (iii) be a woman; and (iv) perform manual handling involving rolling tasks at work. Front-line staff were excluded from participation if they have reported any type of musculoskeletal injury (e.g. lower back pain) to their employer in the last 6 months.

3.2.2. Study design

To determine what factors we should prioritize testing, we consulted with the Director of Care from the LTC site where we conducted the ergonomic evaluation and the Director of Care from LTC site where our research team is conducting the ongoing Flooring for Injury Prevention

(FLIP) Study. Based on these consultations, we examined the effects of three factors: flooring system (concrete+vinyl, compliant+vinyl, concrete+carpet, compliant+carpet), lift type (motor-driven, conventional), and resident weight (average, 90th percentile). Participants completed all 16 conditions; the order in which they performed the conditions was block randomized at each factor level (lift type then flooring system then resident weight).

Flooring system

Four unoccupied resident rooms in the LTC site were renovated, each with a different flooring system: (a) concrete subfloor with vinyl overlay (Eternal Wood, Forbo, Hazleton, United States; heterogeneous construction, 2.0 mm thick; concrete+vinyl), (b) concrete subfloor with carpet overlay (Interface Flor, LaGrange, United States; nylon 50 cm x 50 cm squares, GlasBac backing, 6.0 mm thick; concrete+carpet), (c) novel compliant subfloor (SmartCells, SATech, Chehalis, United States; 25.4 mm thick) with vinyl overlay (compliant+vinyl); and (d) novel compliant subfloor with carpet overlay (compliant+carpet). SmartCells is composed of a continuous rubber surface layer supported by an array of cylindrical rubber columns 14-mm in diameter and spaced at 19-mm intervals [68]. This specific floor, without an overlay, provides 35% [62] and 60% [61] peak force attenuation during mechanical tests that simulate falls to the hip and back of the head, respectively. Compared to other commercially available novel compliant floors, SmartCells has been tested more extensively for balance and mobility and has minimal effects on older adults during daily activities [62,66,68,71,82].

Lift type

We tested two floor-based lifts, one “conventional” (manual-driven*;* Arjo Sara 3000, ArjoHuntLeigh, Gloucester, United Kingdom, ~$7 000 USD) and one “motor-driven” (esense Rise, Indes, Enschede, Netherlands, ~$10 000 USD) (**Figure 3.1, Table A2 in Appendix C**). Both models are examples of floor-based lifts used by direct-care staff when transferring residents capable of partial weight bearing from seating to standing. To ensure wheels were free of debris, lifts were serviced prior to data collection. The novel motor-driven lift works the same way as the conventional lift, but the differences lie in its esense Power Assist system. The manufacturer describes the esense Power Assist system as a “unit with a rotatable drive wheel and a power- and direction-sensitive sensor in the handlebar that enables the direct-care staff to maneuver the hoist with minimal force” [233]. Strain gauges in the handlebar detect the force applied by the hands in the horizontal plane (upward or downward forces are ignored). The component of force that is normal (or perpendicular) to the handlebar determines the power delivered by the drive wheel in the forward and backward directions. The component of force sideways to the handlebar determines the power delivered by the drive wheel in the sideways direction [233].

Resident weight

We obtained the average (67-kg) and 90th percentile (90-kg) weights of Canadian LTC residents from the Canadian Institute for Health Information's CCRS 2014 database of 121,899 residents between January 1 and March 31, 2014. University student volunteers posed as mock residents of average (n = 3) and 90th percentile (n = 4) weight. We weighed mock residents prior to each testing session and, if necessary, added weight via a backpack or ankle weights so each mock resident's weight plus the weight of the instrumented handlebar equaled 67 ± 2 kg or 90 ± 2 kg.

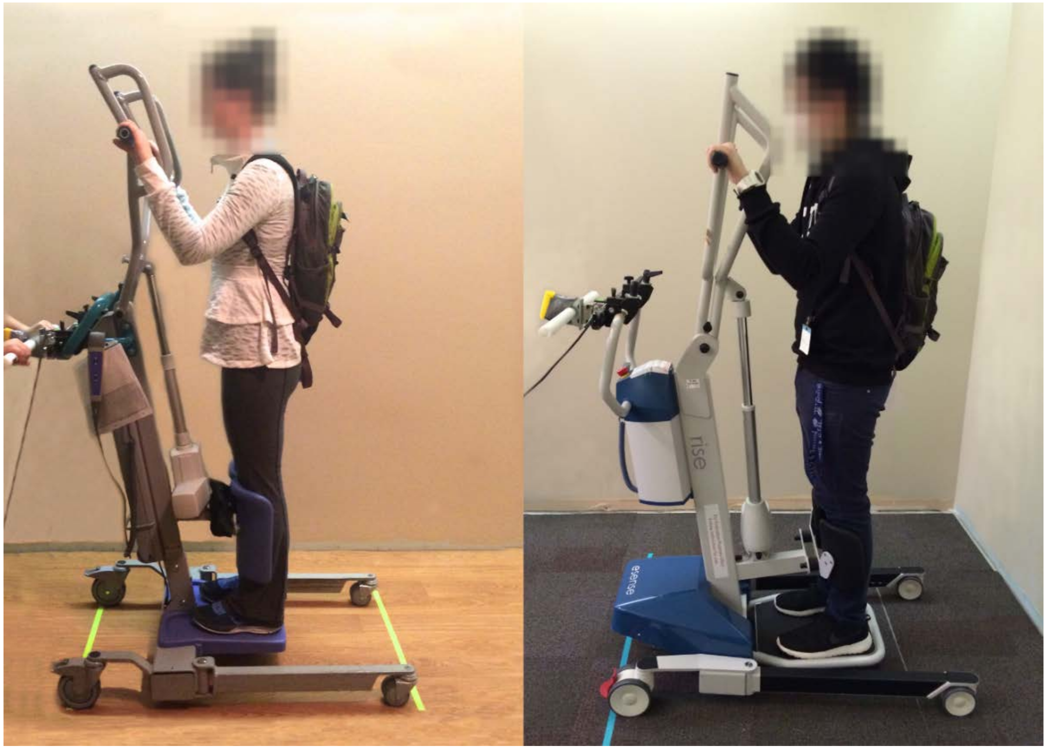

Figure 3.1 Images of the floor-based lifts
Left: A photograph of the conventional lift (Arjo Sara 3000, ArjoHuntLeigh, Gloucester, United Kingdom) loaded with a 67-kg mock resident (university student volunteer). Right: A photograph of the motor-driven lift (esense Rise, Indes, Enschede, Netherlands) loaded with a 90-kg mock resident. To make weight, the mock residents added weight via a backpack so that their weight plus the weight of the instrumented handlebar was equal to either 67 ± 2 kg or 90 ± 2 kg.

3.2.3. Experimental protocol

We measured participant height with a stadiometer (Seca 437, Seca, Hamburg, Germany), weight with a digital scale (Seca bella 840, Seca, Hamburg, Germany), grip strength with a handgrip dynamometer (Jamar Plus, Sammons Preston Rolyon, Bolingbrook, United States), and ascertained demographics and work history by questionnaire.

Participants were randomly allocated to the order in which they performed the conditions, but were not blinded to the independent variables. For each condition, participants performed the pushing task four times (one practice trial and three recorded trials) and were given the same series of instructions. Following a start signal, the participant was asked to push the lift in a straight line by grasping an instrumented handlebar with both hands. We instructed them to push the lift as they normally would when pushing an average or 90th percentile resident, thus replicating manual handling during a typical work shift. Although they were encouraged to push with their habitual form, we emphasized the importance of pushing consistently (form and speed) for all trials of a given condition, and we marked the preferred distance between the lift and the participant's leading foot, foot width, foot depth, and hand position after each practice trial and instructed participants to fix these positions for the remaining three trials of a given condition. Therefore, for each condition, the participant had the same starting posture (hand and foot placement) but was free to move her torso as needed. The push distance was maximized to the length and configuration of each room and ranged from 3.3 to 3.7 meters. We allowed 60 ± 10 seconds of settling time between trials in the NCF conditions during which time the lift was loaded with the mock resident. Because there has been so little research on the specific effects of NCF on the operation of floor-based lifts, we elected to begin this line of investigation by examining a simple straight-line pushing task rather than a more complex turning task. At the end of each experimental condition, participants were asked to rate pushing difficulty over the past three recorded trials on a scale from 1 to 5 (*very easy* = 1, *somewhat easy* = 2, *neither easy nor difficult* = 3, *somewhat difficult* = 4, and *very difficult* = 5). The study protocol was approved by the Research Ethics Boards of the Fraser Health Authority and Simon Fraser University; all participants provided written informed consent.

3.2.4. Apparatus and measurement of external hand forces

We collected hand force data using a piezoelectric, triaxial load cell (model 9074C, Kistler, Winterthur, Switzerland) custom mounted between existing lift frames and a cylindrical handlebar 61.0 cm long and 3.2 cm in diameter (**Figure 3.2**). A level was used to match the height of the instrumented handlebar to that of the original horizontal handholds. We used a USB-6218 BNC Data Acquisition Device (National Instruments, Austin, United States), sampled at 1280 Hz, and a custom MATLAB (Mathworks, Natick, United States) software routine to acquire load cell data on a laptop computer. To acquire the precise orientation of the instrumented handlebar at the start of each trial in order to calculate force data along a consistent set of forward/down/right axes relative to the lift orientation, we used a triaxial accelerometer (Opal, APDM, Portland, United States) sampled at 128 Hz. To validate the accuracy of the instrumented handlebar setup, we mounted it to a force plate (model FP4060-10-2000, Bertec Corp., Columbus, United States) and found a discrepancy of ±3.5 N or less for force components measured when simulating a range of possible push force directions (pushing directly along the load cell's vertical or horizontal axes and at a 45° angle between those axes).

We characterized the initial phase of pushing by the instant of peak forward force (T_{init}), and defined the sustained phase (T_{sust}) as the time interval beginning 1 second after T_{init} and ending 2 seconds before the instant of minimum forward force (T_{min}) (**Figure 3.3**). At T_{init}, we extracted the values for the forward force (F_{init_fwd}), resultant force (F_{init_res}), and downward force (F_{init_dwn}). During the sustained phase (T_{sust}), we extracted the value of the average forward force (F_{sust_fwd}), average resultant force (F_{sust_res}), and average downward force (F_{sust_dwn}). For each participant, we averaged each response variable over all three trials of a given experimental condition and used these trial averaged values for subsequent statistical analyses.

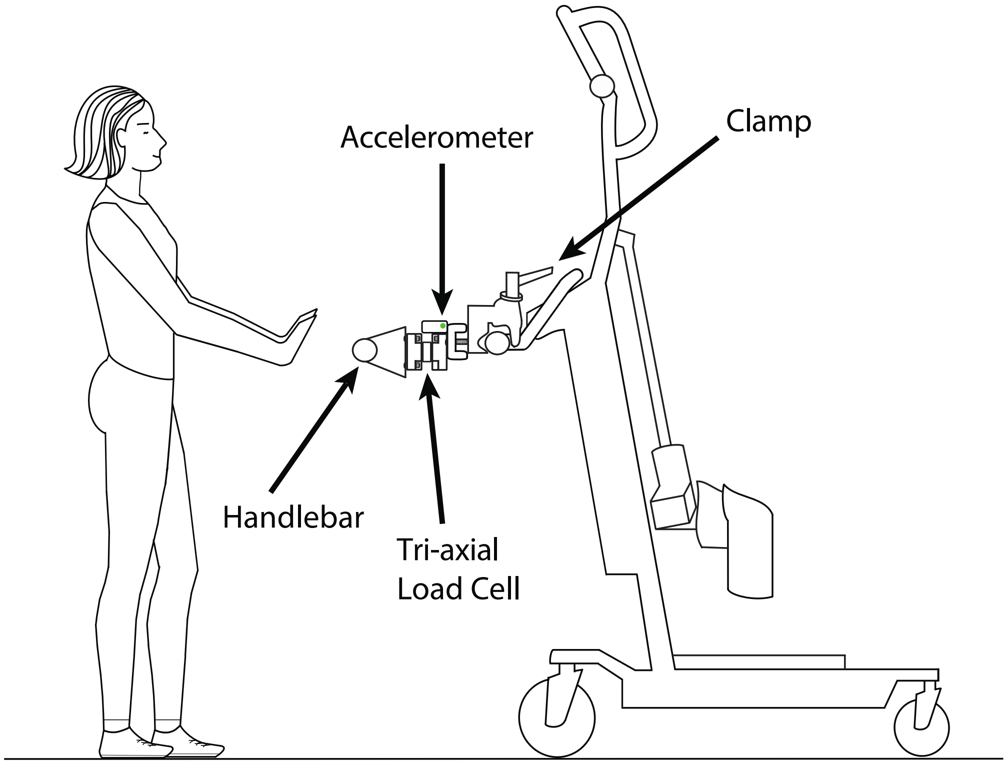

Figure 3.2 Illustration of the experimental setup
This experimental setup was used to measure initial and sustained hand forces, including a conventional floor-based lift affixed with an instrumented handlebar containing a triaxial load cell.

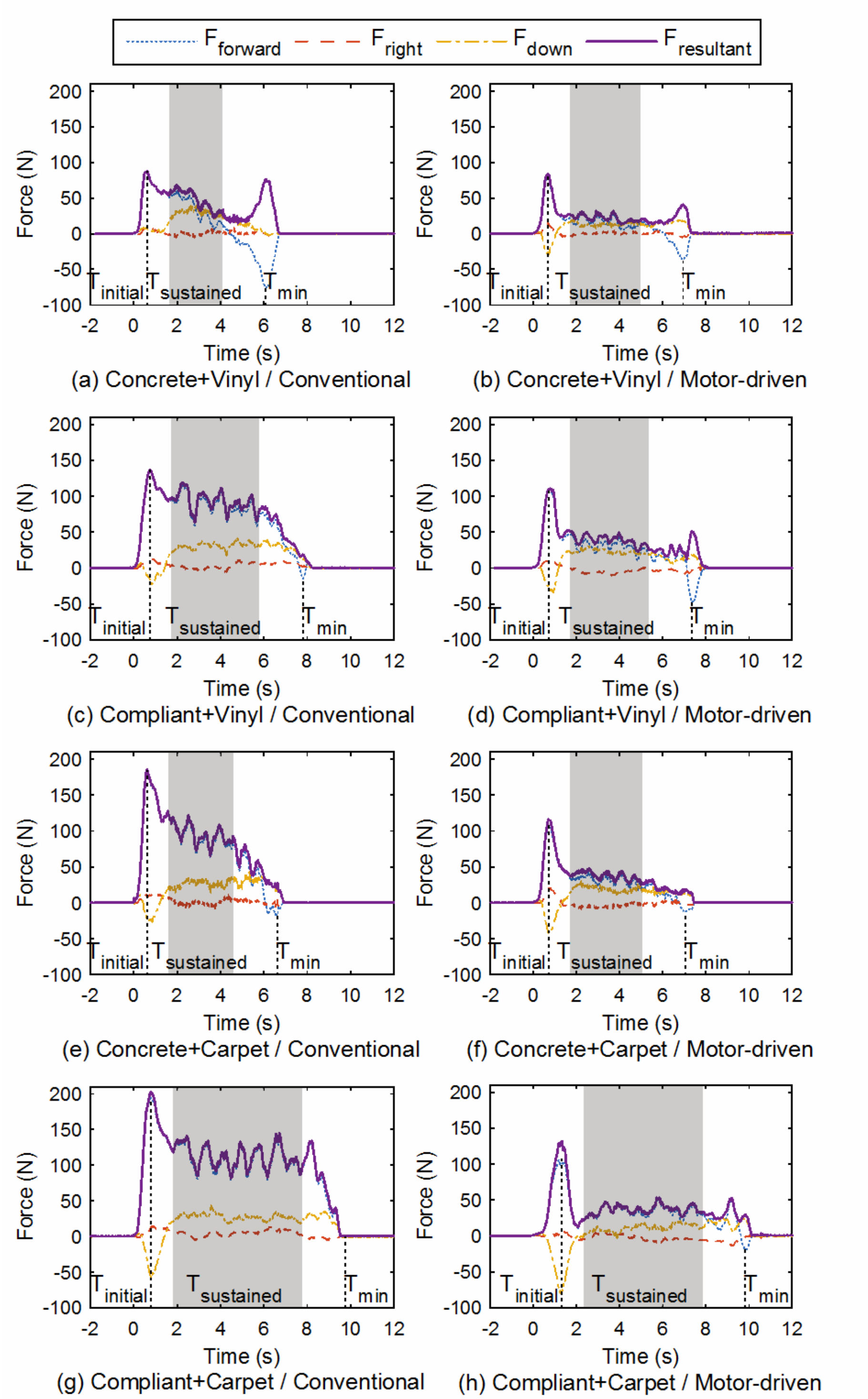

Figure 3.3 Representative force profiles from one participant of a single trial for each experimental condition for the 90th percentile resident weight (90-kg).

Each force profile provides forward force (F_{fwd}), lateral (right) force (F_{right}), down force (F_{dwn}), and resultant force (F_{res}) and indicates time points (a) initial phase of pushing ($T_{initial}$), the instant of peak forward force; (b) sustained phase of pushing ($T_{sustained,}$ shaded in gray), the time interval beginning 1 second after T_{init} and ending 2 seconds before T_{min}; and (c) instant of minimum forward force (T_{min}).

3.2.5. Tolerance limits for pushing

We determined if measured initial and sustained resultant forces exceeded participant-specific tolerance limits calculated from Snook and Ciriello's Hazard Analysis Tool [234]. This validated and widely used tool is based on psychophysically determined maximum acceptable forces to protect against low-back injury [234,235]. Tolerance limits were determined based on participant sex, self-reported pushing distance and pushing frequency during a typical 8-hour workday, and handle height [234]. Using response categories adapted from Snook and Ciriello [234], participants reported the frequency (range: one push every 1 minute to one push every 8 hours) and distance (range: 2.1 meters per push to 61.0 meters per push) they push residents using floor-based lifts during a typical 8-hour workday. Tolerance limits that would accommodate 90% of the female industrial population were extracted in kilograms and converted to Newtons (N) for comparison.

3.2.6. Sample size considerations

We collected pilot data from six female university volunteers of mean age 24.3 (SD = 4.0) years and calculated effect sizes based on these pilot data for all matched comparisons of interest (using paired t-test calculations within GPower) and determined that a sample size of N = 14 would yield ≥80% power with alpha = .05 for all comparisons.

3.2.7. Statistical analyses

We used a 4 x 2 x 2 full factorial (randomized complete block) ANOVA to assess the influence of flooring system, lift type, and resident weight on initial forces (F_{init_fwd}, F_{init_res}, F_{init_dwn}), sustained forces (F_{sust_fwd}, F_{sust_res}, F_{sust_dwn}), and on subjective ratings of pushing difficulty. Participant was treated as a random factor block in all analyses. Significance was defined as $p < .05$. If a significant interaction was found, simple effects were analyzed using Tukey's HSD post hoc (or student's *T* tests, when appropriate). All statistical analyses were carried out using JMP for Mac (JMP Version 11.2.0, SAS Institute Inc., Cary, United States). We report the results of statistical testing for resultant forces (F_{init_res}, F_{sust_res}) in the Results section. Results of statistical testing for forward (F_{init_fwd}, F_{sust_fwd}) and downward (F_{init_dwn}, F_{sust_dwn}) forces are available in **Appendix D**. For post hoc comparisons of two-way interactions, we report mean percentage change between conditions, for descriptive purposes, calculated by averaging participant-specific percentage change between conditions across the third factor.

3.3. Results

3.3.1. Participant characteristics

14 female direct-care staff volunteers (mean age 44.6, SD = 12.4; years; nine health care aides, two licensed practical nurses, three registered nurses) from a 165-bed LTC site in British Columbia, Canada participated in the study (**Table 3.1**). All participants were experienced in using floor-based lifts, and none reported a MSI to their employer in the last 6 months.

Table 3.1 Participant characteristics (N = 14)

	Mean	Standard Deviation	Minimum	Maximum
Age (years)	44.6	12.4	26	68
Height (cm)	159.6	9.3	147.5	180.0
Weight (kg)	78.9	23.5	49.3	125.3
BMI (kg/m^2)	29.7	6.7	21.0	43.4
Grip strength of dominant hand (kg)	26.0	4.9	18.0	38.9
Years working in current position	12.1	10.0	5.0	47.0
Years working in long-term care	13.7	9.0	5.0	41.0

3.3.2. Initial and sustained external hand forces

Unadjusted means of initial (F_{init_fwd}, F_{init_res}, F_{init_dwn}) and sustained (F_{sust_fwd}, F_{sust_res}, F_{sust_dwn}) forces for each experimental condition are provided in **Table 3.2**.

Flooring system x lift type interaction

Independent of resident weight, we observed an interaction between flooring system and lift type on mean F_{init_res}, $F(1, 193) = 15.70$, $p < .001$, and F_{sust_res}, $F(1,193) = 133.27$, $p < .001$.

Effect of novel compliant subfloor. With vinyl overlay, F_{init_res} was, on average, 44.7 N higher (SE = 4.3 N, p < .001, 47.7% increase) on the novel compliant than on the concrete floor when pushing the conventional lift (**Figure 3.4a)**. Similarly, F_{init_res} was 29.8 N higher (SE = 4.3 N,

$p < .001$, 45.8% increase) on the novel compliant than the concrete floor when pushing the motor-driven lift (**Figure 3.4b)**. With carpet overlay, F_{init_res} was 23.0 N higher (SE = 4.4 N, $p < .001$, 14.9% increase) on the novel compliant than the concrete floor when using the conventional lift (**Figure 3.4a)**. With carpet overlay, there was no difference in F_{init_res} ($p = .975$) between novel compliant and concrete floors when pushing the motor-driven lift (**Figure 3.4b)**. In addition, greater F_{init_res} was required to push both the conventional lift (27.7 N, SE = 4.4 N, $p < .001$, 18.0% increase) and motor-driven lift (13.9 N, SE = 4.3 N, $p = .033$, 16.0% increase) over the concrete+carpet floor than the compliant+vinyl floor.

Table 3.2 Unadjusted means (standard deviations) of forward, downward, and resultant forces during initial and sustained phases of motion during straight line pushing of conventional and motor-driven floor-based lifts with average and 90th percentile resident weights

		Conventional Lift		Motor-Driven Lift	
		Average (67 kg)	90th Percentile (90 kg)	Average (67 kg)	90th Percentile (90 kg)
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Initial forces					
F_{init_fwd}	Concrete + vinyl	86.4 (26.2)	97.8 (29.3)	63.2 (13.0)	66.5 (11.5)
	Compliant + vinyl	130.9 (25.6)	151.4 (20.6)	89.5 (13.8)	100.5 (11.6)
	Concrete + carpet*	160.7 (24.7)	177.8 (22.6)	106.1 (9.5)	113.8 (13.8)
	Compliant + carpet	179.3 (21.8)	206.3 (20.0)	117.8 (13.8)	120.4 (19.2)
F_{init_dwn}	Concrete + vinyl	34.8 (32.0)	34.5 (31.2)	10.6 (21.2)	10.8 (19.1)
	Compliant + vinyl	32.8 (30.7)	28.6 (37.1)	3.6 (25.3)	1.8 (27.7)
	Concrete + carpet*	26.2 (36.8)	19.2 (42.1)	- 2.9 (22.7)	- 9.6 (22.1)
	Compliant + carpet	18.2 (44.3)	7.7 (48.5)	-17.8 (33.6)	- 17.2 (32.6)
F_{init_res}	Concrete + vinyl	98.5 (26.9)	109.3 (27.7)	67.9 (13.3)	70.3 (12.0)
	Compliant + vinyl	138.5 (25.9)	158.6 (22.3)	93.1 (14.9)	104.7 (13.3)
	Concrete + carpet*	166.9 (26.7)	183.7 (25.5)	108.8 (9.0)	116.7 (13.8)
	Compliant + carpet	185.9 (25.0)	212.8 (20.7)	123.8 (15.4)	126.1 (21.0)
Sustained forces					
F_{sust_fwd}	Concrete + vinyl	26.1 (14.0)	33.2 (16.6)	16.6 (3.2)	18.5 (2.5)
	Compliant + vinyl	69.2 (4.7)	82.3 (4.5)	29.3 (2.5)	32.4 (3.0)
	Concrete + carpet*	73.5 (4.1)	87.1 (5.0)	28.7 (2.3)	31.8 (2.0)
	Compliant + carpet	87.5 (6.1)	107.1 (4.7)	32.7 (2.1)	37.1 (2.4)
F_{sust_dwn}	Concrete + vinyl	38.2 (14.6)	40.3 (16.1)	31.1 (14.6)	32.5 (13.1)
	Compliant + vinyl	47.0 (19.6)	46.0 (17.4)	33.5 (12.9)	35.1 (15.6)
	Concrete + carpet*	48.0 (20.3)	52.0 (23.7)	34.2 (11.9)	34.7 (14.4)
	Compliant + carpet	53.5 (25.8)	51.4 (24.5)	30.8 (14.8)	31.2 (16.0)
F_{sust_res}	Concrete + vinyl	49.2 (16.5)	55.3 (18.8)	37.2 (12.8)	39.1 (11.8)
	Compliant + vinyl	86.1 (11.2)	96.4 (10.4)	46.1 (10.9)	49.7 (13.2)
	Concrete + carpet*	90.0 (11.8)	104.2 (13.2)	46.2 (10.0)	49.0 (11.0)
	Compliant + carpet	105.3 (17.2)	121.4 (13.4)	46.9 (11.3)	50.7 (11.8)

Note. * n = 13 for conventional lift trials on concrete+carpet as data was missing completely at random for 1 participant.

Similar trends were observed for sustained forces. With vinyl overlay, F_{sust_res} was 39.0 N higher (SE = 1.8 N, $p < .001$, 88.2% increase) on the novel compliant floor than on the concrete floor when pushing the conventional lift (**Figure 3.4c)** and 9.7 N higher (SE = 1.8 N, $p < .001$, 29.0% increase) when pushing the motor-driven lift (**Figure 3.4d**). With carpet overlay, F_{sust_res} was 15.6 N higher (SE = 1.9 N, $p < .001$, 18.7% increase) on the novel compliant than on the concrete floor when pushing the conventional lift (**Figure 3.4c**), but there were no differences in F_{sust_res} ($p = .999$) between novel compliant and concrete floors when pushing the motor-driven lift (**Figure 3.4d**).

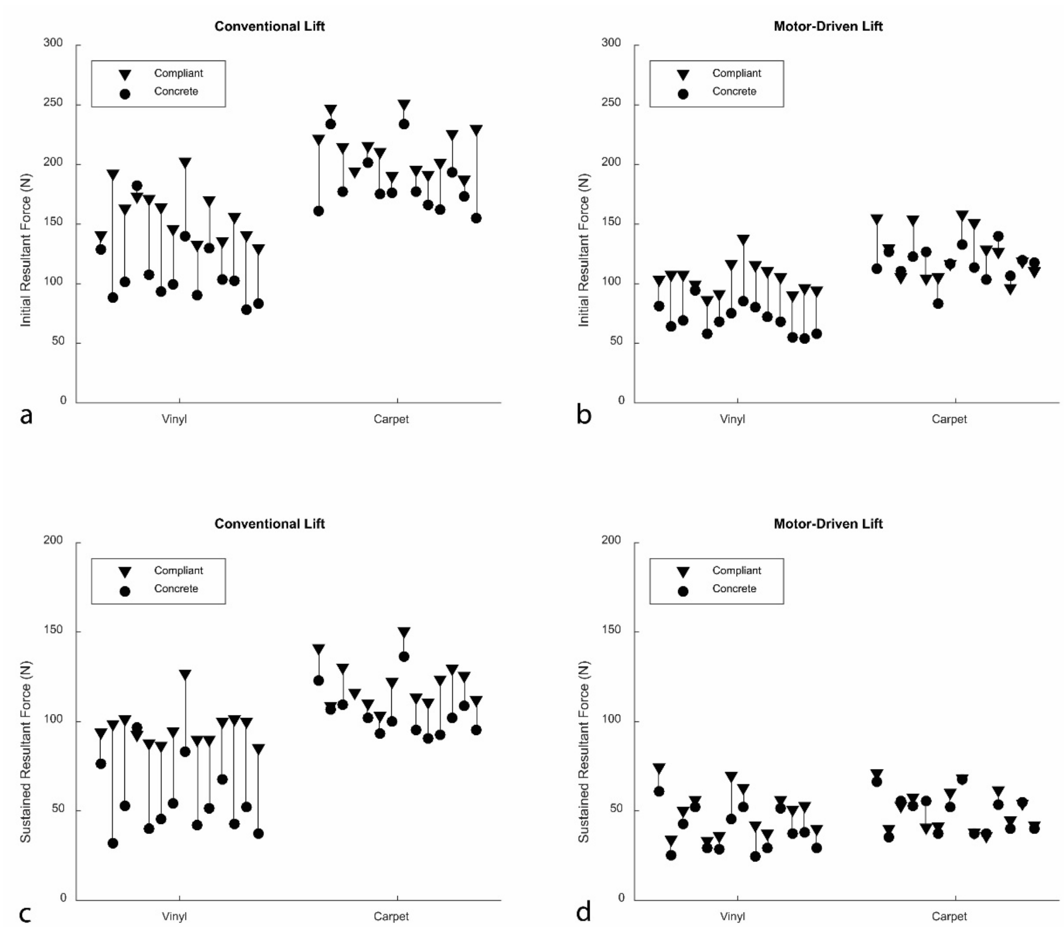

Figure 3.4 Individual participant change in initial resultant forces (top panel) and sustained resultant forces (bottom panel) between the novel compliant subfloor (triangles) and concrete subfloor (circles) for both overlays (vinyl, carpet) when pushing the conventional lift (left panel, plots a and c) and motor-driven lift (right panel, plots b and d) loaded with the 90th percentile resident weight.

Effect of carpet overlay. With concrete subfloor, Finit_res was, on average, 73 N greater (SE = 4.4 N, $p < .001$, 69.7% increase) on carpet than the vinyl overlay when pushing the conventional lift. Likewise, Finit_res was 44 N higher (SE = 4.3 N, $p < .001$, 63.2 % increase) on carpet than on the vinyl overlay when pushing the motor-driven lift. With novel compliant subfloor, Finit_res was, on average, 50.7 N greater (SE = 4.3 N, $p < .001$, 34.1% increase) on carpet than on the vinyl overlay when pushing the conventional lift. With novel compliant subfloor, Finit_res was, on average, 26.1 N greater (SE = 4.3 N, $p < .001$, 26.3% increase) on carpet than on the vinyl overlay when pushing the motor-driven lift.

Similar trends were observed for sustained forces. With concrete subfloor, F_{sust_res} was 46 N higher (SE = 1.9 N, $p < .001$, 87.0% increase) on carpet than on the vinyl overlay when pushing the conventional lift and 9 N higher (SE = 1.8 N, $p < .001$, 24.8 % increase) when pushing the motor-driven lift. With novel compliant subfloor, F_{sust_res} was, on average, 22.1 N greater (SE = 1.8 N, $p < .001$, 24.2% increase) on carpet than on the vinyl overlay when pushing the conventional lift, but there was no difference in F_{sust_res} ($p = .999$) between carpet and vinyl overlays when pushing the motor-driven lift. Participants exerted 6.5 N higher F_{sust_res} on the concrete+carpet floor than the compliant+vinyl floor when pushing the conventional lift (SE = 1.9 N, $p = .015$, 6.4% increase), and there was no difference in F_{sust_res} ($p > .999$) between the concrete+carpet floor and the compliant+vinyl floor when pushing the motor-driven lift.

Effect of motor-driven lift. For all four flooring conditions and both resident weights, every participant applied lower pushing forces for the motor-driven lift than the conventional lift for initial and sustained phases. Independent of resident weight, mean resultant forces were lower for the motor-driven lift than the conventional lift on all flooring conditions (by 34.8 to 74.4 N for initial forces and by 14.1 to 64.5 N for sustained forces).

Resident weight x lift type interaction

We observed an interaction between resident weight and lift type on $F_{init\_res,}$ $F(1, 193) = 8.38$, $p = .004$, and $F_{sust\_res,}$ $F(1, 193) = 22.26$, $p < .001$. Independent of flooring system, F_{init_res} was 18.6 N (SE = 3.1 N, $p < .001$, 13.5% increase) higher and F_{sust_res} was 11.7 N higher (SE = 1.3 N, $p <.001$, 14.3% increase) for the 90th percentile weight than the average weight when pushing the conventional lift. In contrast, there were no differences in F_{init_res} ($p = .200$) and F_{sust_res} ($p = .100$) between the average and 90th percentile weights when pushing the motor-driven lift.

When pushing the motor-driven lift, F_{init_res} was lower by 49.3 N (SE = 3.1 N, $p < .001$, 31.6% decrease) when pushing the average resident weight and 61.9 N lower (SE = 3.1 N, $p < .001$, 35.8% decrease) when pushing the 90th percentile resident weight compared to the conventional lift. The motor-driven lift reduced F_{sust_res} by 38.7 N (SE = 1.3 N, $p < .001$, 43.3% decrease) when pushing the average weight and by 47.4 N (SE = 1.3 N, $p < .001$, 46.7% decrease) when pushing the 90th percentile weight.

3.3.3. Subjective ratings of pushing difficulty

We observed an interaction between flooring system and lift type, $F(1,191) = 23.80$, $p < .001$, and a significant main effect of resident weight, $F(1, 191) = 14.33$, $p < .001$, on mean subjective ratings of pushing difficulty (**Table 3.3)**.

Effect of novel compliant subfloor

With the vinyl overlay, subjective ratings increased by an average of 1.7 points (95% CI 1.17 to 2.27) from 1.3 (*very easy*) on concrete to 3.0 (*neither easy nor difficult*) on novel compliant when pushing the conventional lift, independent of resident weight ($p < .001$). There was no difference, however, in subjective ratings between novel compliant and concrete floors when pushing the motor-driven lift ($p > .999$). With carpet overlay, there was no difference in subjective ratings between concrete and novel compliant floors when pushing the conventional lift ($p = .058$) nor the motor-driven lift ($p = .931$).

Effect of carpet overlay

With the concrete subfloor, subjective ratings increased by an average of 2.2 points (95% CI 1.68 to 2.81) from 1.3 (*very easy*) on vinyl to 3.5 (*somewhat difficult*) on carpet, independent of resident weight ($p < .001$). When pushing the motor-driven lift, subjective ratings increased by an average of 0.6 points (95% CI 0.02 to 1.12) from 1.1 (*very easy*) on vinyl to 1.7 (*somewhat easy*) on carpet ($p = .034$). With novel compliant subfloor, subjective ratings increased by an average of 1.1 points (95% CI 0.52 to 1.62) from 3.0 (*neither easy nor difficult*) on vinyl to 4.1 (*somewhat difficult*) on carpet when pushing the conventional lift ($p < .001$), but there was no difference in subjective ratings between vinyl and carpet overlays when pushing the motor-driven lift ($p = .793$). In addition, there was no difference when comparing the concrete+carpet to the compliant+carpet floor when pushing either the conventional lift (p = .086) or motor-driven lift (p > .999).

Effect of resident weight

Independent of flooring system and lift type, mean subjective ratings for average and 90th percentile weight categories were consistent with the *somewhat easy* category at 2.1 points and in between the categories *somewhat easy* and *neither easy nor difficult* at 2.5 points, respectively (estimated difference = 0.34 points, (95% CI 0.16 to 0.52, p < .001).

Table 3.3 Unadjusted means, standard deviations, and ranges of subjective ratings of pushing difficulty for each flooring condition

	Conventional Lift				Motor-Driven Lift			
Variable	Mean	SD	Min	Max	Mean	SD	Min	Max
Average resident weight category (67 kg)								
Concrete + vinyl	1.2	0.4	1	2	1.1	0.4	1	2
Compliant + vinyl	2.8	1.2	1	4	1.5	0.7	1	3
Concrete + carpet	3.2	1.2	1	5	1.6	0.8	1	3
Compliant + carpet	3.8	1.1	2	5	1.8	0.8	1	3
Ninetieth percentile resident weight category (90 kg)								
Concrete + vinyl	1.4	0.5	1	2	1.1	0.4	1	2
Compliant + vinyl	3.3	1.2	1	5	1.7	0.6	1	3
Concrete + carpet	3.9	1.3	1	5	1.9	0.9	1	3
Compliant + carpet	4.4	0.8	3	5	2.1	1.0	1	4

Note. Response categories were 1 (very easy), 2 (somewhat easy), 3 (neither easy nor difficult), 4 (somewhat difficult), and 5 (very difficult); SD = standard deviation; Min = minimum; Max = maximum.

3.3.4. Comparison to tolerance limits

Participant-specific tolerance limits for pushing were the same for the conventional and motor-driven lifts, since pushing distances (in meters), frequency (number of pushes per 8-hour shift), and handle heights (vertical floor to hands in centimeters) fell within identical categories. A majority of participants reported using floor-based lifts once in an 8-hour shift (57%) over approximately 2.1 meters (93%), and health care aides tended to use the floor-based lifts more frequently (response range: one push every 30 minutes [67%] to one push every 8 hours [33%])

than licensed practical nurses and registered nurses (one push every 8 hours [100%]). Participant-specific tolerance limits ranged from 206 to 216 N (21–22 kg) for F_{init_res} and 108 to 128 N (11–13 kg) for $F_{sust\_res.}$

For both conventional and motor-driven lifts, all participants exerted forces below tolerance limits when pushing average and 90th percentile weights over the concrete+vinyl and compliant+vinyl floors (**Table 3.4**). However, some participants exerted forces above tolerance limits when using the conventional lift to push residents over the concrete+carpet and compliant+carpet floors. In contrast, when pushing average and 90th percentile weights using the motor-driven lift over all flooring systems, force values remained below the tolerance limits for all participants.

As force values were highest on compliant+carpet floor, average safety margins (defined as the average differences between tolerance limits and measured forces) were lower for this floor (54.3 N) than all other floor conditions.

Table 3.4 Number of participants above tolerance limits for safe pushing and safety margins (Newtons) during straight line pushing of conventional and motor-driven floor-based lifts for each flooring condition

		Conventional Lift		Motor-Driven Lift	
		Above Limit	Safety Margin	Above Limit	Safety Margin
		n (%)	Newtons	*n* (%)	Newtons
Average resident weight category (67 kg)					
F_{init_res}	Concrete + vinyl	0 (0)	112.4	0 (0)	143.1
	Compliant + vinyl	0 (0)	72.3	0 (0)	117.8
	Concrete + carpet	**2 (14.3)**	**43.6**	0 (0)	102.1
	Compliant + carpet	**3 (21.4)**	**25.0**	0 (0)	86.4
F_{sust_res}	Concrete + vinyl	0 (0)	68.6	0 (0)	80.5
	Compliant + vinyl	0 (0)	31.6	0 (0)	71.6
	Concrete + carpet	0 (0)	27.0	0 (0)	71.5
	Compliant + carpet	**2 (14.3)**	**12.5**	0 (0)	70.8
Total	Concrete + vinyl	0 (0)	—	0 (0)	—
	Compliant + vinyl	0 (0)	—	0 (0)	—
	Concrete + carpet	**2 (14.3)**	—	0 (0)	—
	Compliant + carpet	**4 (28.6)**	—	0 (0)	—
90th percentile resident weight category (90 kg)					
F_{init_res}	Concrete + vinyl	0 (0)	101.6	0 (0)	140.6
	Compliant + vinyl	0 (0)	52.3	0 (0)	106.2
	Concrete + carpet	**2 (14.3)**	**26.9**	0 (0)	94.2
	Compliant + carpet	**6 (42.9)**	**1.8**	0 (0)	84.1
F_{sust_res}	Concrete + vinyl	0 (0)	62.4	0 (0)	78.7
	Compliant + vinyl	0 (0)	21.4	0 (0)	68.1
	Concrete + carpet	**2 (14.3)**	**12.7**	0 (0)	68.8
	Compliant + carpet	**8 (57.1)**	**3.7**	0 (0)	67.0
Total	Concrete + vinyl	0 (0)	—	0 (0)	—
	Compliant + vinyl	0 (0)	—	0 (0)	—
	Concrete + carpet	**3 (21.4)**	—	0 (0)	—
	Compliant + carpet	**11 (78.6)**	—	0 (0)	—

Note. Data in bold reflect conditions in which observed forces exceeded tolerance limits for at least a single participant. Finit_res = initial resultant force; Fsust_res = average resultant force.

3.4. Discussion

We measured the hand forces exerted by direct-care staff to push floor-based lifts, loaded with two different resident weights, over four flooring systems. Our first hypothesis was that both push forces and subjective ratings of pushing difficulty would be higher on NCF than on standard flooring when using the conventional lift but not the motor-driven lift. Our results supported this hypothesis in most instances. As hypothesized, when using the conventional lift, initial and sustained push forces were significantly higher on novel compliant than on standard (concrete) flooring for both vinyl and carpet overlays. Also as hypothesized, when using the motor-driven lift, we found no difference in initial and sustained push forces between novel compliant and standard flooring for the carpet overlay. We did, however, find unexpectedly that when using the motor-driven lift, initial and sustained push forces were significantly higher on novel compliant than on standard flooring for the vinyl overlay, although the differences between novel compliant and standard flooring were smaller in magnitude than when using the conventional lift.

In terms of subjective ratings of pushing difficulty, when using the conventional lift, participants perceived greater difficulty when pushing over novel compliant compared to standard flooring for the vinyl overlay (which we hypothesized) but not for the carpet overlay (which was unexpected). This result was likely because perceived pushing difficulty over the concrete+carpet floor was quite high to start with (consistent with *somewhat difficult*), so there was limited opportunity for ratings to increase over the compliant+carpet floor. When using the motor driven lift, there were no differences in subjective ratings of pushing difficulty between novel compliant and standard flooring, consistent with our hypothesis.

Our second hypothesis was that push forces and subjective ratings of pushing difficulty would be higher when pushing the 90th percentile compared to the average resident weight when using the conventional but not the motor-driven lift. In support of this hypothesis, we found small but significant increases in initial and sustained push forces between the average and 90th percentile weight categories when using the conventional lift, and no differences when using the motor-driven lift. In addition, mean subjective ratings of pushing difficulty were higher overall for the 90th percentile resident weight category than for the average resident weight category, but this effect was independent of lift type. Consistent with our third and fourth hypotheses, we found that (a) no participants exceeded tolerance limits for straight-line pushing when using the motor-driven lift on any flooring system or for either resident weight, (b) no participants exceeded recommended tolerance limits when straight-line pushing the conventional lift over floor conditions with a vinyl overlay, and (c) some participants exceeded tolerance limits when straight-line pushing the conventional lift over floor conditions with a carpet overlay (concrete+carpet, compliant+carpet). These results are consistent with the finding that the motor-driven lift significantly reduced initial and sustained pushing forces compared to the conventional lift on all floor systems for both resident weights.

The results of our study are important and extend the results from the only previous ergonomic appraisal of NCF [92] in a number of significant ways. We evaluated a commercially available NCF system with previously demonstrated biomechanical efficacy [61,62,66,71,82], included a larger sample size of experienced LTC direct-care staff familiar with the pushing tasks [226], and investigated the effects of resident weight, comparison to tolerance limits, and subjective ratings of pushing difficulty. In addition, we tested a conventional floor-based lift that is used commonly in LTC and a novel, motor-driven floor-based lift that has not been evaluated previously.

This study also has certain limitations. First, we examined a single movement (straight-line pushes) and, therefore, underestimated the biomechanical demands (and force requirements) for direct-care staff to use floor-based lifts. Future research should incorporate tasks of increased complexity that are common in LTC (e.g., pulling and turning in confined spaces) as these tasks can impose greater biomechanical demands on users [221,236]. Second, we examined two different floor-based lift models. Thus, we did not compare the forces required to operate the conventional and motor-driven lifts to an overhead lift. Since previous research has identified that overhead lifts reduce lower back loads imposed on care staff relative to conventional floor-based lifts [221,227], authors of future work should compare the motor-driven lift to an overhead lift. Third, tolerance limits were calculated based on 14 participants from one LTC site. Care staff from other LTC sites may have different tolerance limits as the frequency and distance of pushing floor-based lifts can vary by resident demographics, site-level culture and regulations, building design, and the presence of other transferring aids (e.g., ceiling lifts, sit-to-stand poles, full lifts). Fourth, we kept the height of the instrumented handlebar fixed for both floor-based lifts (101 cm, conventional; 109 cm, motor-driven), which may not reflect realistic conditions in all circumstances. The native handles of both lifts accommodate various handgrip heights to allow the user to select a hand position that he or she feels is most appropriate for the task at hand. Furthermore, users may not always push from the handles, especially when turning. Thus, although we expect resultant (magnitude) forces would be the same (fixed vs. free) when straight-line pushing, our findings may result in more or less downward force depending on participant height (i.e., more downward force for taller participants). Fifth, as study flooring was installed in an active LTC site, we were unable to control for minor dips and peaks in base floor levelness. Although we measured the incline/decline to be minimal along wheel paths (measured at 30-cm intervals and ranging from +1.3° to -0.8° with an average of +0.28° and standard deviation of 0.43°), we cannot be certain of the effect of slope on measured forces. Forces from the concrete+vinyl room may have been artificially low as it was the only floor on a slight downslope (average of -0.04°). Sixth, because direct-care staff are predominantly female [219] we included only women; results many not generalize to men. Finally, results may not generalize to all floor-based lifts, nor should the results be generalized to other flooring systems; the composition of vinyl, carpet tile, and NCF can vary significantly (e.g., thickness and material) by brand.

Despite these limitations, the results of this study collectively demonstrated that SmartCells NCF increased straight-line push forces compared to concrete flooring. However, linear push forces on the compliant+vinyl floor remained below tolerance limits for all participants when using the conventional and motor-driven lifts. On the compliant+carpet floor, push forces exceeded tolerance limits for some participants when operating the conventional lift but not the motor-driven lift. Using a motor-driven lift instead of a conventional lift substantially reduced push forces, ensured that all participants were within tolerance limits for pushing, and decreased subjective ratings of pushing difficulty on novel compliant and concrete floors with vinyl and carpet overlays.

In conclusion, this study provides novel information about the effects of NCF and carpet on forces during pushing tasks in LTC and demonstrates the ability of the motor-driven lift to substantially reduce forces and decrease ratings of pushing difficulty, which may ultimately lead to the prevention of work-related MSIs in LTC sites, especially in locations with NCF and/or carpet.

Chapter 4. Feasibility of Compliant Flooring for Fall Injury Prevention in Long-Term Care: Perceptions of Senior Managers

4.1. Introduction

Given the high incidence of falls and fall-related injuries among older adults in long-term care (LTC) [16,45,115,237], health care stakeholders are increasingly considering the adoption of new technologies to prevent fall-related injuries in LTC. Compliant (low-stiffness) flooring is an emerging technology that aims to prevent injuries from falls in LTC [61]. Decisions by stakeholders to install compliant flooring (in either new or existing LTC sites) will be based not only on understanding of clinical and cost effectiveness, but also of barriers and facilitators to adoption of this technology, as such factors will influence the success of knowledge transfer into LTC practice [103,104].

Previous research on compliant flooring has been predominantly quantitative in nature. Biomechanical studies have consistently reported that specific types of compliant flooring can reduce impact forces at the hip and head during simulated falls without negatively affecting balance and mobility during standing and walking tasks [62,63,66], suggesting intervention efficacy. Preliminary evidence from clinical studies conducted in acute and LTC also suggest that compliant flooring may reduce the incidence and severity of fall-related injuries [86,95,97] in a cost-effective manner [97,100]. Ergonomic studies have identified that maneuvering wheeled equipment over compliant flooring requires more force than over standard flooring [89,92,221], so concurrent interventions may be needed to protect the safety of LTC staff in locations where compliant flooring is installed. To date, previous research has not explored what factors would influence adoption of compliant flooring in LTC by key stakeholders.

The socioecological model [238] identifies five levels of stakeholders that may influence adoption of compliant flooring: individual (e.g., LTC residents), interpersonal (e.g., LTC residents' family and friends, LTC frontline staff), organizational (e.g., senior managers of LTC), community (e.g., housing and care provider associations), and societal (e.g., members of building code committees, government, LTC licensing). Since compliant flooring is an environmental intervention, LTC senior managers are key organizational stakeholders with a critical role in decisions to install compliant flooring in LTC. Accordingly, this study aimed to explore barriers and facilitators to adoption of compliant flooring as a fall injury prevention strategy within LTC from the perspective of LTC senior managers.

4.2. Methods

We conducted in-depth interviews with senior managers from LTC. The reporting for this study was based on the consolidated criteria for reporting qualitative health research (COREQ) checklist [239]. This 32-item checklist is a commonly used tool by qualitative researchers and was developed to promote explicit and comprehensive reporting of qualitative studies, including interviews [239]. We obtained ethics approval for this study from Simon Fraser University (2015s0617) and Fraser Health Authority Research (FHREB 2015-118) Ethics Boards.

4.2.1. Participant selection

We identified prospective participants primarily through our research team's professional networks, and the Recruitment Lead (PML, Fraser Health Co-Investigator) invited them to participate via email. The Recruitment Lead and Project Lead (CCL) also attended two Director of Care meetings (both in January 2016), where they informed prospective participants about the study. Interested individuals contacted the Project Lead directly via email, who confirmed their eligibility and scheduled the interview.

We used purposeful (convenience) sampling techniques [240,241] to recruit individuals from all three LTC funding structures under the jurisdiction of the Fraser Health Authority: owned and operated; contracted – non-profit; and contracted – for profit sites. Owned and operated sites are comprised exclusively of Fraser Health employees. Both types of contracted sites receive funds from Fraser Health to operate, but the staff are employees of the LTC site not Fraser Health. Within the contracted sites, non-profit sites use any surplus revenue to further achieve their purpose or mission, while for profit sites distribute their surplus revenue to the organization's shareholders or equivalent.

In order to participate, individuals must have been actively working in a senior management level position (e.g., Executive Director, Director of Care, Manager, or Resident Care

Coordinator) at a LTC site in the Fraser Health Authority in British Columbia, Canada. Participants had to be involved in the clinical and operational aspects of their respective site, including the implementation of interventions for fall injury prevention. We did not require participants to have previous exposure to or knowledge about compliant flooring.

4.2.2. Data collection

Prior to each interview, we asked participants to complete an informed consent form, explaining the goals of the study, and a demographic questionnaire to ascertain age, sex, job title, highest level of education achieved, years in their current position, years in a LTC senior management position, and duration of career in LTC. We also obtained details about each participant's LTC site. When possible, we obtained this information through the publically available Canadian Institute for Health Information database [242] or Fraser Health's website [243]. Information that was not publically available were asked during the interview (e.g., use of fall and fall injury prevention strategies).

We used a semi-structured approach to create the interview guide and conduct the interview sessions, allowing our interviewer (CCL, woman, Master of Human Kinetics, PhD Candidate) freedom to probe participants' answers for more detail and clarification where appropriate [241]. We used an iterative process and refined the interview guide based on responses from two pilot interviews, discussion among the research team (CCL, VOZ, DCM, FF), and review of a related focus group guide [244], which examined resident and staff perceptions on the decision to use hip protectors. In addition, new probes emerged while conducting the main interviews based on the responses from participants.

The final interview guide consisted of three sections. The first section included open-ended questions and related probes designed to obtain information about the participant and their LTC site (background questions). We began each interview with background questions to ease the participant into the interview and for the interviewer to gain a better understanding of the participant and the LTC site before beginning the main discussion and questions on compliant flooring. The second section included one question asking participants if they had heard about compliant flooring before, with a probe asking them to describe what they knew, if applicable. The interviewer then used a script to define compliant flooring and briefly describe current research evidence about compliant flooring to the participant. The interviewer recited this script to participants whether or not they had previous knowledge of compliant flooring for two reasons: (1) we wanted to use this opportunity to concisely disseminate knowledge about compliant to LTC senior managers, and (2) we wanted to ensure that all participants received the consistent messaging about compliant flooring before asking the main interview questions. Finally, the third section of the interview guide included open-ended questions and related probes designed to understand the participants' perceptions of compliant flooring, including perceived factors functioning as organizational barriers to and facilitators of implementing compliant flooring (see **Table 4.1** for main interview questions).

A single, face-to-face interview was conducted with each participant by the same trained researcher (CCL; January – March 2016). A second researcher (VOZ, woman, Bachelor of Science Candidate) assisted by taking field notes to capture observations that may not have been obtained from the audio recordings (e.g., nonverbal reactions of participants). Neither researcher had any relationship with any participant prior to the commencement of the study. Interviews lasted an average of 53 minutes (SD = 8.9; range: 38 – 73 minutes) and were conducted at the participants' workplace, usually in their office with the door closed. Participants were able to speak freely and comfortably when answering all questions during the interview.

All interviews were digitally recorded. CCL and VOZ independently recorded post-interview field notes and then merged them into one field note file per interview, which provided supplementary information about the interviewers' perspective.

Table 4.1 Main questions from interview guide

Section 1: Background questions

- Please describe your LTC site.
- Please describe the funding structure of your LTC site.
- In a few sentences, please describe your current job responsibilities.
- Please briefly describe the strategies that are currently being used at your LTC site to prevent falls among residents.
- Please briefly describe the strategies that are currently being used at your LTC site to prevent fall-related injuries among residents.
- Please describe the types of flooring systems/materials that are in your LTC site.

Section 2: Previous knowledge of compliant flooring

- Have you ever heard of novel (or purpose-designed) compliant flooring as a strategy for preventing fall-related injuries?

Script for describing compliant flooring

- A potential strategy for reducing the incidence and severity of fall-related injuries is to install compliant flooring, which decreases the ground surface stiffness and the subsequent forces applied to the body parts at impact.
- Purpose-designed compliant flooring (also called 'low stiffness flooring,' 'dual-stiffness flooring,' and 'safety flooring') is a padded layer, generally found beneath vinyl or carpet.
- Laboratory studies have demonstrated that compliant flooring can reduce the peak force applied to the hip during a simulated sideways fall by up to 35% and to the head during a simulated backwards fall by up to 60%, without substantially impairing balance (static or dynamic) or mobility of older adults. These laboratory results should translate into an injury reduction in the clinical setting.
- Preliminary clinical findings suggest compliant flooring may reduce fall-related injuries in LTC and acute care settings but we do not know for sure if it reduces injuries in long-term care.

Questions related to knowledge and perceptions of compliant flooring:

- What do you believe are the advantages of having compliant flooring in your LTC site?
- What do you think are the main concerns (potential disadvantages) for implementing compliant flooring in your LTC site?
- In your opinion, what do you think the front-line staff (care aides, nurses, resident care coordinators, and facilities management) will think about compliant flooring?
- I now have an understanding of what you believe are barriers and facilitators of installing compliant flooring in long-term care sites. Now, what is your overall assessment or impression of compliant flooring?

4.2.3. Data analysis

We used JMP 12 software (SAS Institute) to calculate descriptive statistics about the participants and LTC sites. We used NVivo 11.2.2 software (QSR International) to manage and code all interview data, including transcripts and field notes. Analysis of interview data was guided by the thematic framework method [245,246] using an inductive approach; we used specific questions for a-priori topics (i.e., barriers to and facilitators of implementing compliant flooring) for a predetermined population (i.e., LTC senior managers) [247]. Thus, we were able to describe and interpret what was happening in a particular setting (i.e., LTC) [246,247] through the experiences of the targeted participants. Consistent with the framework method for the analysis of qualitative data in multi-disciplinary health research, we analyzed our data using seven steps: (i) transcription, (ii) familiarisation with the interview (iii) coding, (iv) developing a working analytical framework, (v) applying the analytical framework, (vi) charting data into the framework matrix, and (vii) interpreting the data [245]. These are briefly described below.

All digitally recorded interviews were fully *transcribed* verbatim by a professional transcriptionist, then de-identified using participant and LTC site pseudonyms and reviewed for accuracy by a research team member (VOZ, CCL). Transcripts were not returned to participants, and they provide feedback on the findings. Research team members (CCL, VOZ, DCM) and an external qualitative methodology expert (NL) independently read three randomly selected transcripts to *familiarize* themselves with the interviews. Afterwards, each member independently conducted line-by-line, open *coding* for the three transcripts. We then met to compare and discuss the codes that we applied. We worked to agree on specific codes and derived themes from the data, to *develop a working analytical framework* [245]. Two researchers (CCL, VOZ) independently applied this working analytical framework to the same three transcripts and compared coding and discussed disagreements with a third researcher (DCM) to arrive at a consensus. For the remaining 15 transcripts, one researcher (CCL) *applied the analytical framework* to code each transcript and then *charted data into a framework matrix*. A second pass of all codes were performed by a reviewer (VOZ or CCL) to ensure they were appropriately applied. The research team then pulled together key characteristics of the data, mapped, and *interpreted the data set as a whole* [246]. Rigor was enhanced throughout data analysis process analytic memo writing (e.g., writing notes about emerging codes and the thematic framework to capture the analytic process), audit trails (e.g., recording decisions being made throughout data collection and analysis), and peer debriefing (e.g., team meetings) [245,248]. We used the field notes to aid with recall of each interview before reading and coding the related transcript.

For presentation of results, we defined factors that were discussed by less than 25% of participants with the pronoun *few*, between 25% and 49.9% as *some*, between 50% and 74.9% as *many,* and ≥ 75% as *almost all* [249] Factors that were discussed by at least 50% of participants were deemed as central themes and/or subthemes (evidence of saturation); accordingly, we limited elaboration of results to central themes and subthemes.

4.3. Results

4.3.1. Participant characteristics

We interviewed 18 LTC senior managers through 16 interviews (i.e., 14 interviews with one participant, two interviews with two participants). Participants had a mean age of 52.7 years (SD = 9.0 years; range: 37 – 66 years old) and 83% were women (n = 15), and were relatively experienced working in LTC (**Table 4.2**). We had equal representation of participants across the three funding structures within the Fraser Health Authority. Over 70% of participants (n = 14) had previous knowledge of compliant flooring, and almost 40% (n = 7) had previous exposure to compliant flooring, which ranged from 'I have seen compliant flooring before' to 'I currently have compliant flooring at my LTC site.'

4.3.2. LTC site characteristics

Participants represented 16 LTC sites throughout the Fraser Valley in British Columbia (**Table 4.3**). Almost all sites were large with an average of 152 beds. Every site had traditional flooring systems installed (e.g., linoleum, vinyl, carpet); one site had compliant flooring installed previously in a common area. All sites used a variety of fall and injury prevention strategies (e.g., hip protectors, implementation of the health authority's vitamin D and calcium protocol, falls mats, and bed and/or chair alarms).

Table 4.2 Participant characteristics by funding structure

	Total (N = 18)	Owned & Operated by Fraser Health Authority (n = 6)	Contracted, Not-for-Profit (n = 6)	Contracted, For-Profit (n = 6)
Age, years, mean (SD)	52.7 (9.0)	50.7 (7.5)	57.0 (10.2)	50.5 (9.1)
Women, N (%)	15 (83.3)	4 (66.7)	5 (83.3)	6 (100.0)
Job Title, N (%)				
Executive Director	1 (5.6)	0 (0.0)	1 (16.7)	0 (0.0)
Director of Care	11 (61.1)	0 (0.0)	5 (83.3)	6 (100.0)
Manager	5 (27.8)	5 (83.3)	0 (0.0)	0 (0.0)
Resident Care Coordinator	1 (5.6)	1 (16.7)	0 (0.0)	0 (0.0)
Highest Level of Education, N (%)				
Associate Degree (College)	1 (5.6)	0 (0.0)	0 (0.0)	1 (16.7)
Bachelor's Degree	8 (44.4)	2 (33.3)	3 (50.0)	3 (50.0)
Master's Degree	9 (50.0)	4 (66.7)	3 (50.0)	2 (33.3)
Clinical background, N (%)	17 (94.4)	6 (100.0)	5 (83.3)	6 (100.0)
Years Working in Current Position, mean (SD)	5.6 (3.9)	3.7 (2.4)	7.8 (4.5)	5.2 (3.8)
Years Working in a Management Position, mean (SD)	11.1 (7.3)	7.7 (9.3)	12.0 (5.0)	13.5 (6.7)
Years Working in Long-term Care, mean (SD)	19.4 (10.9)	14.8 (8.0)	17.8 (9.8)	25.5 (12.9)
Previous Knowledge about Compliant Flooring, N (%)	13 (72.2)	4 (66.7)	5 (83.3)	4 (66.7)
Previous Exposure to Compliant Flooring, N (%) *	7 (38.9)	0 (0.0)	4 (66.7)	3 (50.0)

Note. All data was derived from the demographic form administered immediately before conducting the interview.
* Previous exposure to compliant flooring ranges from 'I have seen compliant flooring before' to 'I currently have compliant flooring at my LTC site'.

Table 4.3 Long-term care site characteristics by funding structure

	Total (N = 16)	Owned & Operated by Fraser Health Authority (n = 5)	Contracted, Not-for-Profit (n = 5)	Contracted, For-Profit (n = 6)
General LTC Site Characteristics				
Size, N (%) *				
Medium (30 – 99 beds)	1 (6.3)	0 (0.0)	0 (0.0)	1 (16.7)
Large (> 99 beds)	15 (93.7)	5 (100.0)	5 (100.0)	5 (83.3)
Number of Beds, mean (SD) †	151.9 (49.7)	182.2 (47.3)	126.2 (25.6)	148.2 (59.2)
Number of Publically Subsidized Beds, mean (SD) †	122.3 (45.4)	171.0 (38.9)	94.8 (30.5)	104.7 (27.2)
Urban Location, N (%)*	16 (100.0)	5 (100.0)	5 (100.0)	5 (100.0)
Resident Length of Stay, years, mean (SD) *	2.5 (0.8) ‡	2.8 (0.9)	2.7 (0.6)	2.1 (0.8) ‡
General LTC Resident Characteristics, mean % of residents (SD) *				
> 85 years of age	57.8 (10.2)	60.8 (9.0)	57.0 (10.3)	56.5 (12.1)
< 65 years of age	4.1 (2.8)	4.3 (1.6)	4.1 (3.6)	4.1 (3.2)
Women	66.6 (5.0)	69.0 (3.0)	64.6 (5.4)	66.6 (5.8)
Dementia	57.2 (12.1)	46.8 (6.5)	59.4 (11.5)	62.2 (12.6)
Use of Fall Related Injury Prevention Strategies, N (%) §				
Compliant Flooring	1 (6.3)	0 (0)	0 (0)	1 (16.7)
Fall Mats	15 (93.8)	5 (100.0)	4 (80.0)	6 (100.0)
Hip Protectors	16 (100.0)	5 (100.0)	5 (100.0)	6 (100.0)
Helmets	3 (18.8)	0 (0)	2 (40.0)	1 (16.7)
Hi-Low Beds	9 (56.3)	3 (60.0)	2 (40.0)	4 (66.7)
Use of Fall Prevention Strategies, N (%)§				
Vitamin D/Calcium	16 (100.0)	5 (100.0)	5 (100.0)	6 (100.0)
Exercise Programs	13 (81.3)	4 (80.0)	5 (100.0)	4 (66.7)
Walking Programs	10 (62.5)	5 (100.0)	2 (40.0)	3 (50.0)
Staff Education	12 (75.0)	3 (60.0)	4 (80.0)	5 (83.3)

Bed Alarms	15 (93.8)	5 (100.0)	4 (80.0)	6 (100.0)
Chair Alarms	12 (75.0)	5 (100.0)	3 (60.0)	4 (66.7)
Use of Overhead/Ceiling Lifts, N (%) §	12 (75.0)	5 (100.0)	4 (80.0)	3 (50.0)
Safety Indicators, mean % of residents (SD) *				
Falls in the last 30 days (2014 - 2015)	12.7 (3.7)	12.9 (1.8)	14.2 (5.1)	11.5 (3.3)
Falls in the last 30 days (2010 - 2015) ||	14.1 (6.7) ¶	11.0 (3.0)	17.7 (9.3)	13.0 (4.0) ¶
Worsened Pressure Ulcer (since previous assessment)	4.1 (1.4)	4.7 (1.2)	4.4 (2.0)	3.3 (0.8)
Appropriateness and Effectiveness Indicators, mean % of residents (SD) *				
Daily Restraint Use	10.3 (10.2)	5.6 (3.6)	14.9 (9.9)	9.6 (12.8)
Potentially Inappropriate Use of Antipsychotics (definition: residents taking antipsychotic drugs without a diagnosis of psychosis)	26.2 (7.8)	23.8 (8.9)	25.6 (7.4)	28.3 (8.3)
Resident Health Status Indicators, based from previous assessment, mean % of residents (SD) *				
Improved Physical Functioning	29.0 (7.4)	22.4 (4.3)	33.3 (5.8)	29.9 (7.8)
Worsened Physical Functioning	31.3 (3.9)	29.4 (1.2)	32.6 (2.9)	31.5 (5.5)
Worsened Depressive Mood	10.8 (4.0)	11.1 (4.4)	13.4 (2.5)	8.5 (3.9)
Experiencing Pain	13.5 (6.5)	18.7 (5.8)	12.9 (7.4)	10.6 (4.8)
Experiencing Worsened Pain	9.5 (4.4)	10.7 (2.3)	12.5 (4.9)	6.3 (3.2)

* Data from Canadian Institute for Health Information[242]

† Data from Fraser Health[243]

§ Data from interview transcripts

‡ Length of Stay data missing for 1 LTC site (contracted, for profit)

|| Fall data averaged over a 5-year period

¶ 2012-2013 falls data missing for 1 LTC site (contracted, for profit)

4.3.3. Thematic results

Three major themes emerged from the interviews, which were identified as organizational facilitators to adoption of compliant flooring, organizational barriers to adoption of compliant flooring, and general organizational considerations about compliant flooring (**Table 4.4**). Every participant discussed each theme.

Table 4.4 Themes and subthemes related to adoption of compliant flooring from the interviews

Theme	Subtheme	Participants N (%)	Descriptive Pronoun
Organizational Facilitators	Injury prevention	18 (100.0)	Almost all
	LTC staff's openness to change	13 (72.2)	Many
	Financial considerations – funding availability and cost savings	11 (61.1)	Many
	Benefits to LTC frontline staff	8 (44.4)	Some
	Implementation in a new build (versus retrofit)	6 (33.3)	Some
	Improved flooring performance	5 (27.8)	Some
	Improved perceptions of care home	4 (22.2)	Few
	Increased resident mobility	3 (16.7)	Few
Organizational Barriers	Negative effects to LTC frontline staff	16 (88.9)	Almost all
	Financial considerations – cost and lack of funding	16 (88.9)	Almost all
	Lack of research evidence	8 (44.4)	Some
	Installation challenges	7 (38.9)	Some
	Resident mobility challenges	5 (27.8)	Some
	LTC staff's resistance to change	4 (22.2)	Few
General Organizational Considerations	Uncertainties about clinical effectiveness	17 (94.4)	Almost all
	Unknown effects for LTC staff	16 (88.9)	Almost all
	Uncertainties about flooring performance	14 (77.8)	Almost all
	Uncertainties about funding availability and cost of implementation	11 (61.1)	Many
	Uncertainties about LTC staff's openness to change	11 (61.1)	Many
	Uncertainties about how it will affect resident mobility	10 (55.6)	Many
	Unknowns about installation and retrofit	4 (22.2)	Few
	Unknowns of marketing compliant flooring to recruit residents	3 (16.7)	Few

Organizational facilitators to adoption.

Several organizational facilitators may promote the uptake of compliant flooring in LTC (**Table 4.4**). The most saturated subthemes were injury prevention, LTC staff's openness to change, and financial considerations (i.e., funding availability and cost savings; **Table A3 in Appendix E**).

Participants spoke at length about the important role compliant flooring may have to reduce the number and severity of injuries in LTC, with reducing hip fractures and head injuries as the most important. Participants discussed how preventing injuries may lead to subsequent important outcomes, such as a decrease in acute care visits, surgeries, and other negative consequences from falls.

> *Absolutely, if you can reduce the quote unquote damage or severity of the injuries from the falls, because let's face it, I've seen people that have had a hip fracture and they come back and die. They get some kind of pneumonia. They're not able to get up anymore. They're not able to mobilize. Depression sets it. So again, all those good things [i.e., care] that you've done over the last year and a half or however many months, just goes right down the chute. –Maya*

The notion that compliant flooring could improve the overall safety of residents through "built in protection" was a strong benefit for participants. Participants explained how compliant flooring may be superior to other common fall injury prevention strategies, as it provides more coverage than hip protectors (protects body parts other than the hip) and fall mats (covers larger surface areas).

> *Definitely because then, you know, they can actually fall anywhere. It doesn't have to be in that square [fall mat surface area] because we have residents who can actually walk a few steps. They already walk past the floor mat before they fell. So that's certainly an area that if the whole room is protected, for sure that would be actually helpful. –Emma*

The openness of LTC staff to change was identified as a key facilitator for the uptake of compliant flooring, and was characterized as willingness of LTC front-line and administration to adapt to change. Participants emphasized that their front-line staff and upper management are supportive of improving care of the residents through new interventions:

> *A very general statement about our staff culture is, they generally get on board with things they see are good for the residents. And I think it would be pretty hard-- I just can't see them not being on board with compliant flooring that may help reduce injuries to residents. –Jake*

Financial considerations emerged as an important subtheme, including both access to funding to purchase and install compliant flooring and potential financial savings that would be realized after installing compliant flooring. These financial-based facilitators were discussed more by participants from contracted – non-profit LTC sites (5 of 6 participants) and contracted – for profit (4 of 6 participants) than owned and operated sites (2 of 6 participants). Access to funding was a key facilitator, illustrated by many participants (n = 11) stating, when prompted, that they would install compliant flooring if they did not have to incur any material or installation costs. Participants also highlighted that there are ways to obtain funding from their regional health authority and foundations, along with designating some of their annual budget to fall injury prevention strategies. Participants commented that, once installed, compliant flooring may reduce the overall health care costs for the health authority, via reduction in the number of hospitalizations, surgeries, invasive procedures, etc., and may result in the health authority providing more funding to LTC sites to support further installations of compliant flooring. A few participants also commented that LTC sites might save money after installing compliant flooring by not needing to purchase other equipment that they believed to be less effective than compliant flooring, such as fall mats.

Organizational barriers to adoption.

Several organizational barriers emerged that may hinder the uptake of compliant flooring (**Table 4.4**). The most saturated subthemes were negative effects to LTC care staff and financial considerations (i.e., cost and lack of funding). Participants most frequently identified the following anticipated consequence of installing compliant flooring: a softer floor will result in care staff having to push or pull harder when using medical equipment and devices that roll over the flooring, including floor-based (sit-to-stand) lifts, carts, and wheelchairs. This was viewed as a potential work hazard for care staff. We probed participants to see if having a ceiling lift or a motor-driven floor-based lift would alleviate their concerns about using conventional floor-based lifts over compliant flooring. Ceiling lifts were believed to be a potential solution, but they have limited coverage in most LTC sites and are not recommended when residents are able to partially weight bear. Furthermore, the motor-driven floor-based lift was believed to be a suitable solution, but participants were concerned about its cost and what other ergonomic solutions would be required and available for other rolling devices.

Two financial considerations were discussed by most participants: the cost of the flooring (materials and installation), and the lack of funding available for purchasing and installing the flooring. These financial-based barriers were voiced by most participants (16 of 18 participants), regardless of the LTC funding structure they came from (owned and operated: 5 of 6 participants; contracted – non-profit: 6 of 6 participants; contracted – for profit: 5 of 6 participants).

> *The two disadvantages I would see is obviously cost. Cost associated with the initial install. That would be the only issue. And of course maintenance costs of cleaning it and maintaining it. And my only other concern really is the effect of heavy equipment on the floor. –Harrison*

General organizational considerations about compliant flooring.

We identified many general inquiries about compliant flooring and its performance, which we considered as neutral statements rather than facilitators or barriers. This theme comprised the most saturated subthemes including uncertainties about: clinical effectiveness, effects for LTC staff, flooring performance, funding availability and cost of implementation, LTC staff's openness to change, and how compliant flooring will affect resident mobility. Participants asked several questions about the number and types of injuries that would be reduced, indicating their uncertainty about the clinical effectiveness of compliant flooring. Before advocating for widespread implementation of compliant flooring, participants stated their preference to wait for the results from an ongoing randomized controlled trial of compliant flooring in a local LTC site and to view an existing LTC site with compliant flooring and/or pilot test the flooring in their own site. There was also uncertainty about how well LTC staff would accept compliant flooring, overlapping with further uncertainty about how it may affect the staff's ability to use rolling equipment without increasing their risk of musculoskeletal injury. Participants also had several inquiries about flooring performance, including maintenance, durability, hygiene, aesthetics, and acoustics.

> *I'd be interesting to know if, over the long term, the product breaks down or becomes less effective over time. –Fitzgerald*

Participants inquired about the effects of compliant flooring on mobility of residents, such as ability to self-propel wheelchairs, perception or balance changes while walking, and if it would improve comfort while walking. Finally, participants communicated their uncertainty about how much the flooring would cost and whether they would receive enough funding to implement it (from health authority, government, etc.), which ultimately affected their overall perception about its feasibility in their care home.

Nonetheless, when asked about their overall assessment of compliant flooring at the end of the interview, 88% (n = 15) were positive and 12% (n = 2) were indecisive (missing data: n = 1).

4.4. Discussion

We used semi-structured interviews to explore barriers and facilitators to adoption of compliant flooring as a fall injury prevention strategy within LTC among 18 senior managers. Participants reached broad consensus on their perceptions of compliant flooring, and three themes about compliant flooring emerged: organizational facilitators to adoption, organizational barriers to adoption, and general organizational considerations about compliant flooring.

Participants identified organizational facilitators and barriers to the adoption of compliant flooring that have been previously reported in the scientific literature, including injury prevention [86,95], financial considerations [97], and positive and negative effects to frontline staff [88,89,92,250]. Injury prevention was the most discussed facilitator, which is consistent with the purpose of compliant flooring [61,62] and reflects the significant and persistent challenge of preventing fall-related injuries in LTC [51,53,54]. Therefore, results from recently completed [86,94,95,251] and ongoing [101] clinical studies of compliant flooring will be especially important in guiding future decisions about adoption of compliant flooring. Furthermore, many participants spoke at length about financial barriers related to compliant flooring. Indeed, compliant flooring costs substantially more to purchase and install than standard flooring [252]. But, consistent with past literature that has examined the cost-effectiveness of compliant flooring [252], participants also suggested that compliant flooring could result in meaningful cost savings for health care systems secondary to injury prevention. Thus, trade-offs between the upfront costs to implement compliant flooring and the expected longer-term cost savings will likely factory heavily in future decisions about compliant flooring installation. Lastly, although participants suggested compliant flooring might increase walking comfort for LTC frontline staff (which is supported by evidence [88,253,254]), the number one barrier to adoption of compliant flooring was the potential negative effect that compliant flooring may have on LTC frontline staff, such as increasing the difficulty of moving heavy equipment over the floor (e.g., loaded floor-based lifts). Given that previous evidence substantiates this concern and indicates that compliant flooring increases the difficulty for health care staff to perform standard tasks, including maneuvering equipment (e.g., floor-based lifts, wheelchairs, beds, patient trolleys), compared to standard flooring [252], an important direction for future research is to identify and test proposed solutions to this problem of maneuvering equipment [252].

Our analyses also revealed novel barriers and facilitators to adoption of compliant flooring that have not been mentioned in existing literature, including the openness (or resistance) of LTC staff to change; lack of published evidence on flooring performance metrics; and the value of the flooring in marketing to attract new residents. Regarding openness of LTC staff, no research has directly explored how to increase acceptance compliant flooring among LTC staff,, but similar lines of inquiry have been examined for other health-related interventions in LTC, such as hip protectors [12]. A systematic review on facilitators of and barriers to hip protector acceptance and adherence in LTC revealed that caregiver-related (i.e., LTC staff) factors were one of the four major themes affecting acceptance and adherence of hip protectors [12]. In particular, caregivers are more likely to accept hip protectors if they understand the value of hip protector use (i.e., reduce risk of injury at the hip in the event of a fall) and have positive attitudes about the effectiveness of hip protectors [12]. Thus, educating LTC staff about the value of compliant flooring may help build openness to change and foster positive attitudes about compliant flooring. Moreover, participant queries about performance metrics of compliant flooring, including durability, hygiene and acoustics, highlights the need for flooring manufacturers to make this type of information readily available in their product information materials. Finally, a few participants believed that compliant flooring could improve perceptions of a care home and attract new residents, as it would be an indicator of higher quality of care. This may prove to be an especially important facilitator for privately operated LTC sites, but these were not the focus of the current study.

General inquiries about compliant flooring mostly represented a lack of knowledge about compliant flooring among LTC senior managers, rather than a lack of research evidence. Some general inquiries could be partially answered with existing evidence (e.g., unknown effects of LTC staff [89,92,221]). In addition, only some participants (n = 8) believed there was a lack of research evidence, which suggests that participants believe the evidence is available, but they may not know how to access it. These findings indicate an opportunity for further knowledge translation and dissemination efforts to share research findings from compliant flooring studies with LTC senior managers and other stakeholders involved in fall injury prevention in LTC. For instance, online and/or in-person education sessions, structured on principles of behaviour change [256], could address common inquiries about compliant flooring raised by study participants.

Our study adds to a nascent body of literature on knowledge translation in LTC. Despite the increasing amount of knowledge translation being conducted across a range of health care settings, the state of knowledge translation in LTC is underdeveloped [109]. A scoping review of knowledge translation studies revealed that only 30 of 1709 (1.8%) primary research articles were conducted in LTC [109]. These 30 studies primarily focused on evaluating knowledge translation interventions, which were conducted to facilitate the uptake of *effective* interventions into practice and/or policy [112]. Our approach was distinct from previous knowledge translation interventions, as we engaged in early-stage integrated knowledge translation before clinical and cost-effectiveness of compliant flooring has been established. Conducting early-stage knowledge translation, in tandem with the conduct of clinical and cost-effectiveness trials, should improve future dissemination of trial findings and implementation of compliant flooring, if appropriate, and improve the design of future trials. This approach could serve as a model for other researchers aiming to increase knowledge uptake efforts within LTC. Together, these actions will aid in closing the knowledge to practice gap [103] and contribute toward reducing the rates of fall-related injuries in LTC at a faster pace, decreasing the health care dollars spent on the falls epidemic.

4.4.1. Limitations

Our results represented the perceptions from one stakeholder group (i.e., organizational-level); therefore, important information may have been missed by not involving stakeholders from individual, interpersonal, community, and societal levels of the socioecological model [238], including individuals representing health care, industry, government, and research. We interviewed participants from all three funding structures within one local health authority and included individuals with and without experience with compliant flooring. The LTC sites participating in our study were representative of other LTC sites throughout Fraser Health Authority, British Columbia and Canada, based on several key indicators (e.g., safety, appropriateness and effectiveness, and resident health status)[242]. However, we cannot be certain that our results represent the opinions and perceptions of LTC senior managers from other funding structures (e.g., private pay LTC sites), other parts of Canada or other countries. Future research could address these limitations. Finally, participants mentioned that there are many research gaps that need to be explored to better understand whether compliant flooring will be feasible within the LTC environment. Though we touched on the types of research that need to be conducted, we did not specifically ask the participants to rank their most important research gaps. Future studies should incorporate a ranking process to help prioritize directions for future research to aid in closing of the knowledge-to-action gap (i.e., the transfer of research findings into practice).

4.4.2. Conclusion

This is first study to use qualitative methods to uncover organizational-level perceptions of factors that influence the uptake of compliant flooring in LTC. By seeking input from LTC senior managers, we provide evidence about important facilitators and barriers that stakeholders consider when deciding to install compliant flooring in LTC, such as injury prevention, effects to LTC frontline staff, financial considerations, and LTC staff's openness to change. Overall, the majority of participants believed compliant flooring would be positive for LTC. Finally, we identified an opportunity for knowledge translation efforts to inform LTC senior managers about the currently available evidence on compliant flooring.

Chapter 5. Feasibility of Compliant Flooring in Long-Term Care: Results of a Stakeholder Symposium

5.1. Introduction

Falls and fall-related injuries among older adults are common and costly. Approximately 30% of community-dwelling adults aged 65 years and older will fall each year with 10-15% of these falls resulting in serious injury [16,42,257,258]. In the long-term care (LTC) setting, 60% of older adults fall each year, and rates of injury are two to three-fold higher than those among the community-dwelling population [115]. The consequences of falls among older adults exert a large financial burden on the health care system, including annual direct costs of $3.4 billion in Canada [1] and $34 billion in the United States [107]. Thus, there is an urgent demand to reduce the incidence and severity of fall-related injuries. Ninety-five percent of hip fractures in older adults are due to falls [18,30]. About 25% of hip fracture patients die within one year of fracture, and approximately 50% are unable to return home or live independently after being discharged from hospital [18,30]. While age-adjusted rates of hip fracture has levelled recently, the rate of traumatic brain injuries due to falls has tripled over the past decade [18,34]. Traumatic brain injuries are now responsible for over half of all fall-related deaths in older adults [18,34]. Survivors of fall-related traumatic brain injuries are at risk of increased morbidity and mortality and decreased quality of life [41].

Compliant flooring represents a unique intervention for fall injury prevention in settings where falls are common, such as LTC (which we define as homes for older adults where personal and nursing care is provided on a 24-hour basis [12]). Compliant flooring offers the potential to reduce the incidence and severity of fall-related injuries by decreasing the stiffness of the ground and the forces applied to the body parts that impact the ground [61]. Thus, compliant flooring is an intervention specifically targeted at reducing the adverse consequences of fall events (i.e., injury prevention) rather than preventing falls from occurring. Compliant flooring has the potential to reduce the incidence and severity of fall-related injuries at all body sites that impact the ground. Furthermore, compliant flooring is a passive intervention, since its effectiveness does not rely on user adherence once it is installed [61,259].

Compared to hip protectors, exercise and pharmaceuticals, compliant flooring is a newer intervention directed at fall injury prevention, and it has not yet been broadly implemented in LTC or other health care settings. Nevertheless, there is a considerable body of scientific evidence about compliant flooring, including studies on biomechanical efficacy [62,63,66], clinical effectiveness [65,67,86,95], cost effectiveness [97,100], and workplace safety [89,92,221]. To facilitate the uptake and application of this evidence about compliant flooring in LTC settings, the Knowledge-to-Action Framework [103,104] underscores the importance of identifying relevant stakeholders, assessing the barriers and facilitators faced by stakeholders to using the relevant evidence, and tailoring research questions to address problems identified by stakeholders. In the LTC setting, stakeholders from health care, research, and industry are involved in making decisions about fall injury prevention strategies, and past research on compliant flooring has engaged stakeholders from each of these sectors [101,259]. However, there is limited understanding about stakeholder perceptions of the advantages and disadvantages to implementing compliant flooring and about the research questions that stakeholders deem most important to address in the future. To address these knowledge gaps, we hosted a 1-day stakeholder symposium with two primary objectives: (i) to identify the advantages and disadvantages of implementing compliant flooring in LTC from the perspective of a diverse group of key stakeholders, and (ii) to identify the most pressing research gaps in the available evidence and related directions for future research on compliant flooring from the perspectives of these key stakeholders. Our secondary objective was to gather feedback about the usefulness of the stakeholder symposium format as a knowledge translation activity.

5.2. Method

5.2.1. Attendees and study design

We hosted a 1-day stakeholder symposium at Fraser Health Authority Headquarters (Surrey, British Columbia, Canada) in September 2016. We recruited attendees, from our existing professional networks, to represent a broad audience of stakeholders from health care (e.g., LTC, acute care, regional health authorities), industry (e.g., flooring manufacturing, interior design), and research. We invited clinicians, allied health practitioners, researchers, interior designers, industry partners, health managers and regulators. Attendees were not required to have any background knowledge or experience with compliant flooring.

The day began with a keynote address presented by an international expert in prevention of injury and disease. The talk focused on the use of environmental interventions to improve older adults' mobility and functional independence, and prevent fall-related injuries. Following the keynote, content experts led a series of podium presentations to disseminate up-to-date evidence about compliant flooring on the following topics: how compliant flooring works, including an overview of the mechanics; the current available evidence related to compliant flooring, based on a summary of results from a scoping review; the push forces required to use floor-based lifts over compliant flooring, based on results from an ergonomic evaluation; and the perceived feasibility of compliant flooring from the perspectives of LTC senior managers, based on results from an interview study. Each presentation was followed by a facilitated question and answer period.

Following the podium presentations, we led an afternoon workshop to identify advantages and disadvantages of implementing compliant flooring in LTC, and to identify gaps in the available evidence and directions for future research about compliant flooring, from the perspectives of the symposium attendees. All attendees were invited to participate in the workshop and were considered equal contributors in all discussions. Attendees were classified based on their occupation into four broad stakeholder subgroups: LTC management (directors, managers), clinical (medical, allied health professionals, LTC resident care coordinators/front-line staff); health authority (facility planners, consultants, managers); and research and industry (researchers, instructors, flooring industry representatives). Our intention was to provide an opportunity for related stakeholders to work together and to provide an environment where attendees would feel comfortable participating in the table discussions.

Each table was set up to have 5 – 6 attendees and was moderated by a workshop facilitator to ensure everyone contributed. Workshop facilitators were trained to ask three key questions about compliant flooring in the LTC setting: *(1) What do you believe are the advantages of having compliant flooring? (2) What do you believe are the potential disadvantages (main concerns) for implementing compliant flooring? (3) What other information would be useful to you (i.e., identify key gaps in the research evidence)?* The first two questions were previously asked to LTC senior managers in the form of semi-structured interviews in a previous study (Chapter 4); we added the third question based on the recommendations for future research from that study.

To help ensure that everyone contributed to the session, attendees were asked to record their answers to each question on sticky notes, from their own perspectives and experiences based on their job position. Attendees were encouraged to write down as many advantages, disadvantages, and gaps as they could (~5 minutes per topic). All attendees received handouts of the podium presentation slides and a plain language summary of the existing compliant flooring evidence; they could refer to these materials as they worked. The sticky notes for each of the three topics were collected by the facilitator and displayed and organized by theme on a poster board so that the group could all see. Each group then collectively ranked their top 3 advantages, disadvantages, and gaps and one attendee from each table presented their group's top 3 selections to all attendees as part of a closing discussion section of the workshop. All sticky notes from the workshop session were retained; each group had different colour sticky notes so we could later identify which concepts came from each group. We concluded the day by having attendees complete an event evaluation form.

5.2.2. Data collection

We collected data before the symposium, during the workshop portion of the symposium, and at the end of the symposium. Leading up to the symposium, we emailed all attendees to obtain demographic information using a pre-event form. We asked attendees to indicate their job title, place of work, how their job or place of work is involved in preventing injuries among older adults, and why they chose to attend the symposium. During the symposium, we retained all sticky notes from the workshop and also recorded each group's top three selections of advantages, disadvantages, and research gaps. At the end of the symposium we asked each attendee to complete a 2-page post-event evaluation form, informed by Wathen and colleagues [260]. The self-administered post-event form asked attendees to provide additional demographic information and rate their perceptions of the symposium, including overall usefulness, to evaluate outcomes of our knowledge translation strategy [104]. We also asked questions about anticipated knowledge use (i.e., did you learn something during the symposium? If yes, do you plan to share what you learned with others and/or plan to change behaviour?) [104]. Finally, we asked each attendee to list what they considered the biggest advantage, disadvantage, and research gap related to compliant flooring; this was a member checking strategy [261] to ensure the data obtained from the workshop included the major opinions of all attendees.

5.2.3. Data analysis

We used JMP 12.0.1 software (SAS Institute) to calculate all descriptive statistics from the pre-event and post-event forms and NVivo 11.2.2 software (QSR International) to code and manage all long-form data obtained from the pre-symposium data collection, workshop, and event evaluation form.

The data from the sticky notes were considered the main data to inform our results. The lead analyst (CCL) used a thematic approach [241,262] by first developing initial codes from all individual sticky notes collected from the workshop (n = 209). The analyst then refined these codes to form themes and subthemes that were used to develop a thematic framework [262,263]. The themes and subthemes were then compared with the top three advantages, disadvantages, and research gaps identified collectively by each group during the workshop and by each participant based on their responses on the event evaluation forms. This analysis step was performed to ensure the top-ranked advantages, disadvantages, and research gaps identified by the groups were captured in the framework, as a way of member checking. Due to the format of the workshop, all themes were discussed by all workshop groups. In order for a code to be considered a subtheme, at least one workshop group had to classify it within their top three ranked advantages, disadvantages, and research gaps. Subthemes were then ranked based on their identified importance by the workshop groups (i.e., injury prevention was ranked as number 1 for all groups = top ranked subtheme; benefits to care staff was ranked as number 2 for three groups = second ranked subtheme, etc.). All analyses performed were reviewed by the senior author (DCM). Examples of our coding scheme are presented in **Table 5.1**.

Table 5.1 Examples of the coding scheme used in data analysis

Subtheme Code	Description of Subtheme Code	Examples from Participants
Injury prevention	• Reduced incidence of injuries • Reduced severity of injuries	"…makes the environment safer for ALL residents." – *Clinical group*
Cost	• Cost of flooring • Availability of funding for flooring and additional equipment requirements	"…requires expensive equipment to move on the floor" – *LTC management group*
Uncertainties about cost-effectiveness	• Cost-analysis/cost-benefit/cost-effectiveness/total cost/cost model • Cost assessment of direct and indirect costs • Determine return on investment	"cost-effective[ness] findings typically based on hip fracture prevention…what about other injuries?" – *Research and industry group*

5.3. Results

5.3.1. Demographics of attendees

Twenty-three stakeholders attended the Symposium. Of these attendees, 23 (100%) completed the pre-event form, 17 (73.9%) attended the workshop, and 21 (91.3%) completed the post-event form. Six attendees were unable to attend the afternoon workshop due to work demands. Attendees had a mean age of 50.4 years (SD = 11.3 years; age range: 30 – 68 years) and 70.0% were women (n = 16). Attendees *primarily* represented LTC (34.8 %, n = 8), regional health authorities (26.1%, n = 6), research (17.4%, n = 4), industry (17.4%, n = 2), and acute care (4.3%, n = 1) (**Table 5.2**). Some attendees identified with more than one sector. Based on a self-reported, 5-point scale, attendees were relatively knowledgeable about fall and injury prevention strategies and compliant flooring before the symposium. All attendees worked in either British Columbia (87.0%, n = 20) or Ontario (13.0%, n = 3).

5.3.2. Identified advantages, disadvantages, and research gaps

Three main themes (i.e., advantages, disadvantages, and research gaps), each with five subthemes, emerged from the workshop data (**Table 5.3**).

Perceived advantages of implementing compliant flooring in LTC

Attendees identified several potential advantages associated with implementing compliant flooring in LTC (**Table 5.3**). Attendees believed the most important advantages of compliant flooring were reducing injuries in residents who have sustained a fall, the potential benefits to care staff, and the potential to increase the quality of life for residents. Of secondary importance, the group suggested that potential health care savings and improved perceptions of the care home were additional advantages.

Table 5.2 Demographics of attendees

Measure	N = 23
Age, years, mean (SD)	50.4 (11.3)
Women, N (%)	16 (70.0)
Sector, N (%)	
Long-term care	8 (34.8)
Health authority	6 (26.1)
Research	4 (17.4)
Industry	4 (17.4)
Acute care	1 (4.3)
Highest level of education, N (%)	
College diploma	2 (8.7)
Bachelor's degree	8 (34.8)
Master's degree	8 (34.8)
PhD	4 (17.4)
Medical degree	1 (4.3)
Years working in current position, mean (SD)	10.2 (9.2)
Previous involvement with researchers hosting the symposium, N (%)	
I was not aware of the research group until being invited to the symposium	2 (9.5)
I was aware of the research group but not much else	2 (9.5)
My colleague or someone I know had been involved in research projects with this research group	3 (14.3)
I had personally been involved in research projects with this research group	14 (66.7)
Previous knowledge of fall and injury prevention strategies, scale 1 (low) to 5 (high), mean (SD)	4.2 (1.1)
Previous knowledge of compliant flooring, scale 1 (low) to 5 (high), mean (SD)	3.6 (1.2)

Note. Data missing for 2 attendees for the following items: years working in current position, previous involvement with researchers hosting symposium, previous knowledge of fall and injury prevention strategies, and previous knowledge of compliant flooring.

Table 5.3 Perceived advantages and disadvantages of implementing, and research gaps in the available evidence about compliant flooring in LTC, ranked in order of importance

Theme	Subtheme
Advantages of implementing compliant flooring	1. Injury prevention
	2. Benefits to care staff
	3. Increased quality of life for residents
	4. Potential health care savings
	5. Improved perceptions of care home
Disadvantages of implementing compliant flooring	1. Cost
	2. Lack of research evidence
	3. Installation challenges
	4. Repercussions involving care staff
	5. General concerns about flooring performance
Research gaps about compliant flooring	1. Uncertainties about cost-effectiveness
	2. Uncertainties about clinical effectiveness
	3. Uncertainties about biomechanical efficacy
	4. Uncertainties about flooring performance
	5. Uncertainties about workplace safety

For the injury prevention subtheme, attendees highlighted that compliant flooring may reduce the number of fall-related injuries and the severity of fall-related injuries should a fall occur, including serious injuries like hip fractures and head injuries. Attendees believed compliant flooring may be superior to other injury prevention intervention strategies, such as hip protectors, as it has the ability to reduce injuries for any body part that impacts the ground by providing high force attenuation. Attendees also affirmed that compliant flooring enables the environment to be safer for all residents and may also reduce injuries from falls sustained by LTC staff and families and friends of the LTC residents who visit the care home.

Attendees perceived that compliant flooring may provide important benefits to care staff. If residents have fewer fall-related injuries following the implementation of compliant flooring, staff will likely experience reduced stress and workload (i.e., fewer injuries results in reduced paper-work and post-fall investigations), and will have more time to focus their energy on other quality issues. Attendees mentioned that compliant flooring may also reduce fatigue of the care staff when walking or standing on the flooring. Attendees suggested that compliant flooring may also help to stimulate the further development and use of technology (e.g., lifting equipment) to compensate for the increased forces required for care staff to maneuver equipment over compliant flooring. This is further described in the perceived disadvantages section below.

Attendees also suggested that compliant flooring may improve the quality of life for residents. They stated this may occur, in part, as a direct downstream effect of injury prevention. Attendees also remarked that by having compliant flooring installed in LTC, residents (and their family members) may have an improved sense of security and safety, and residents may in turn increase their mobilization throughout the care home. Thus, residents may experience a decreased fear of falling and increased physical activity levels and independence. The group also suggested that compliant flooring may improve resident autonomy by replacing other interventions that residents and staff may not want to use (e.g., bedside mats that may cause tripping, hip protectors that residents do not want to wear, and pharmaceutical interventions).

Coinciding with a reduction in fall-related injuries, attendees discussed the important role that compliant flooring might play in reducing overall health care costs. This is based on the assumption that by reducing the number of serious injuries sustained by the residents, there will be a reduced number of hospital transfers and admissions, resulting in a reduction of health care dollars spent on fall-related injuries. In addition, if compliant flooring reduces injuries, attendees proposed that care homes with compliant flooring may be viewed as more desirable by the public; one means of achieving this could be using this flooring as a marketing tool by advertising the site as an innovative and proactive care home.

Perceived disadvantages of implementing compliant flooring in LTC

Attendees identified several potential disadvantages of implementing compliant flooring in LTC, classified into five subthemes. The biggest perceived disadvantages were cost, lack of research evidence, and challenges with installation (i.e., renovation of existing

LTC sites). Of slightly less importance, the group expressed that they were concerned about repercussions involving staff and had general concerns about flooring performance.

Attendees ranked cost as the number one disadvantage associated with compliant flooring. Cost was described in a multitude of ways, including the cost of the material itself (relative to standard flooring), installation, maintenance, and additional equipment costs (e.g., purchasing motor-driven floor-based lifts to replace conventional floor-based lifts) to account for the decreased stiffness provided by compliant flooring versus standard flooring. Attendees were also concerned with who would provide the LTC care sites with the funding and how the costs of the flooring could be justified.

Collectively, attendees believed that the lack of research was a disadvantage for them. Attendees believed that more research needs to be performed before considering widespread implementation of compliant flooring in LTC. Specific examples of perceived unknowns include effects on balance, long-term utility (i.e., how well it works in real life), and clinical effectiveness.

The group of attendees remarked that installing compliant flooring in an existing care home could present significant challenges. It would be disruptive for residents and staff. If a care home decided to renovate only a portion of the total floor surface, the need would arise for installation of transitional ramps to account for height differences between the standard flooring and the compliant flooring system. Some of the attendees commented from personal experiences that these transitional areas can make it more difficult for residents to walk (with and without mobility aides) and may increase the risk of tripping for both residents and staff.

The attendees voiced concern that the implementation of compliant flooring in LTC may have potential repercussions for care staff. Specifically, they were aware that a floor with a lower stiffness would increase the rolling load resistance when care staff to push or pull equipment and possibly increase the risk of care staff sustaining musculoskeletal injuries. In addition, attendees were uncertain if all staff would want to adopt this type of injury prevention strategy.

Attendees also brought up general concerns about flooring performance. Namely, attendees were apprehensive of its durability, maintenance requirements, and sustainability in comparison to standard flooring. In addition, the attendees acknowledged that the flooring will only have the ability to protect body parts that impact the floor, and not body parts that may impact walls or furniture before impacting the ground.

Research gaps in the available evidence

Attendees indicated that they still have uncertainties about cost-effectiveness, clinical effectiveness, biomechanical efficacy, flooring performance, and workplace safety of compliant flooring. The most emphasis was placed on the need for additional knowledge on cost-effectiveness and clinical effectiveness.

A commonly discussed topic during the workshop was the lack of available evidence related to the cost-effectiveness of compliant flooring. Attendees indicated they would like additional cost-benefit and/or cost-effectiveness analyses performed to help determine whether compliant flooring should be installed in LTC. Attendees suggested that future economic analyses should include potential cost savings due to prevention of other injuries in addition to hip fractures (e.g., head injuries, wrist fractures), since most cost analyses have been performed by only considering hip fractures [96–100]. Other ideas presented included the following: performing cost assessments for both direct and indirect costs of injurious falls, determining the financial life cycle of the product, and determining the cost-effectiveness of compliant flooring in low-income environments when compared to standard flooring.

Second to cost-effectiveness, attendees suggested the need for more research to determine the intervention’s true clinical effectiveness in the form of longer (in duration) and/or larger (number of participants) randomized controlled trials. Attendees stated they would like to see more results from trials conducted with the population(s) of interest (i.e., older adults in LTC) and multiple types of injuries (e.g., hip fractures, head injuries, and wrist fractures). Attendees also mentioned that it would be worthwhile to determine whether certain environments (e.g., adult day cares, acute care, LTC) or populations (e.g., stroke patients, dementia residents) would benefit more from compliant flooring than others. Attendees were also curious about whether compliant flooring would increase mobilization, decrease fear of falling, or increase the incidence of falls in LTC residents.

Attendees were interested to know more about the effects of compliant flooring on dynamic balance tasks and gait performance, including individuals that may have neurological deficiencies (e.g., stroke). Attendees also were interested in associations between compliant flooring and point loading (e.g., cane use) and non-vertical forces (e.g., rolling resistance of medical equipment). Complementary to this, attendees also suggested there is an evidence gap on what types of equipment should be modified to ensure that the care staff are able to work safely over compliant flooring. Attendees mentioned the need to directly measure whether there is an increase in workplace injuries after installation of compliant flooring. They also discussed the need for manufacturers to optimize the 'dual stiffness' characteristics of the flooring so that it is soft enough to reduce falls but rigid enough to not impair walking. Finally, attendees had general uncertainties about durability, hygienic properties, effect on the environment, and sustainability of available compliant flooring systems.

5.3.3. Attendees' perceptions of symposium

The majority of attendees ranked the symposium high in terms of its relevance to their current work, benefit of meeting colleagues and exchanging information about compliant flooring, level of comprehension of the material presented, overall quality of discussion and dialogue at the symposium, and overall satisfaction of symposium (**Table 5.4**). All of respondents stated they learned something by attending the symposium (100%, n = 21). Of these respondents, 95.2% (n = 20) stated they plan to share what they learned with others and 42.9% (n = 9) planned to change their behaviour.

Table 5.4 Attendee's perceptions of symposium

Variable	Mean	SD	Min	Max
Relevance to attendee's current work	4.6	0.7	3	5
Benefit of meeting colleagues and exchanging information about compliant flooring	4.7	0.5	4	5
Level of comprehension of the material presented	4.8	0.4	4	5
Overall quality of discussion and dialogue at the symposium	4.9	0.4	4	5
Overall satisfaction of symposium	4.9	0.4	4	5

Note. Response categories ranged from 1 (low) to 5 (high); Responses based from 21 stakeholders; SD = standard deviation; Min = minimum; Max = maximum.

5.4. Discussion

Although a growing body of literature has suggested that compliant flooring may be a viable fall injury prevention strategy in LTC, little is known about the perceptions held by key stakeholders who are responsible for making decisions about fall injury prevention strategies. Guided by the Knowledge-to-Action Framework [103,104], we conducted a 1-day stakeholder symposium attended by 23 stakeholders representing health care, research, and industry. The majority of attendees were knowledgeable about fall and injury prevention strategies, including compliant flooring, prior to attending the symposium. We used an interactive workshop approach to obtain and rank attendees' perceptions of the advantages and disadvantages of implementing compliant flooring and research gaps in the available evidence about compliant flooring in the LTC setting. We also asked attendees whether our selected knowledge translation activity, a stakeholder symposium, was worthwhile for them to attend.

Our findings suggest that while stakeholders perceive compliant flooring to potentially add value to the LTC setting, there also remain significant informational and financial barriers to the uptake of compliant flooring. There appeared to be general agreement on a range of advantages, disadvantages, and research gaps between the pre-assigned workshop groups.

The prevention of fall-related injuries in residents was ranked as the number one advantage for implementing compliant flooring, which is consistent with the overall purpose of compliant flooring systems [61]. These findings are also consistent with the compliant flooring interview study conducted by our research group with LTC senior managers (Chapter 4). Wright and Laing [61] emphasized that compliant flooring is an intervention approach that precludes the need for active user compliance and adherence to ensure effectiveness, compared to hip protectors, exercise, and pharmacological agents. Similarly, symposium attendees also believed that a passive injury prevention strategy such as compliant flooring is a key advantage when considering a new intervention. Attendees advocated that compliant flooring may reduce fall injuries among individuals other than residents (i.e., staff, family and visitors of residents). To our knowledge, this advantage has not been previously mentioned in the published literature and suggests compliant flooring may be beneficial to individuals outside of the target user group.

Attendees ranked ‘benefits to care staff’ as the second most important advantage of compliant flooring. Previous literature has already identified that compliant flooring may increase staff comfort during walking [88], but attendees provided additional insights of how it may benefit care staff. For example, if there is an overall decrease in fall-related injuries in the care home (by residents and others), the care staff may experience reduced workload and lower stress levels. This is an important and previously undocumented advantage, as LTC care staff are subject to considerable work-related stress and report high levels of burnout [264]. Attendees ranked ‘increased quality of life’ for residents as the third most important advantage. If compliant flooring is installed throughout a LTC site or in ‘hot spots’ where falls occur very frequently, residents may feel safer, which may reduce their fear of falling and increase their mobilization thus improving their overall quality of life. To our knowledge, this has not been previously documented in the literature. Furthermore, attendees believed compliant flooring might improve resident autonomy by replacing interventions that residents and/or staff may not want to use. However, this perceived advantage for improved quality of life of residents could also have negative consequences for the residents if sites decided to then not adhere to standard practice guidelines (e.g., stop using hip protectors).

When considering the drawbacks, cost was ranked by attendees as the number one disadvantage. It has been previously documented that compliant flooring costs more than standard flooring [62,96–100]. However, there was discussion at the symposium about the complexities of providing a business case for compliant flooring in Canada: the potential benefits of compliant flooring are realized as health care savings by the government, yet currently the implementation decision and expense is left to individual LTC sites. Thus, it may be hard for LTC sites in Canada to implement compliant flooring, as most do not have the funding or resources to install the flooring on their own, and they will not directly realize any cost savings provided by the flooring. Second, some attendees believed there were too many unknowns to consider implementing compliant flooring at this time. This concern overlaps with research gaps, which are further elaborated on below. Third, attendees believed installing compliant flooring in an existing building would be particularly challenging. Those who had previous experience with a retrofit installation voiced that a successful renovation requires considerable planning and support from LTC administration staff, front-line (care) staff, maintenance staff, and residents' family members. In addition, because retrofit installations require significant time and money to complete, the more prepared the care home is, the less disruptive it will be to its residents.

Of the several research gaps identified by attendees, most emphasis was placed on the uncertainties around cost-effectiveness and clinical effectiveness. Though the symposium included a summary presentation of the available cost-effectiveness evidence, the amount of information available in the literature was unsatisfactory for attendees. Thus, to expand on the available literature, more research is warranted to determine the conditions under which specific types of compliant flooring are cost-effective, especially when considering all injuries avoided versus only hip fractures avoided. In addition, further research establishing the setting-specific clinical and financial impacts would help clarify the business case for compliant flooring in LTC. Attendees were also dissatisfied with the amount of clinical evidence available and were hoping to hear about results from larger and longer randomized controlled trials, from multiple settings (e.g., LTC, acute care). This demonstrates the need for more clinical trials to provide additional evidence about compliant flooring. Attendees also felt that future research should consider examining dynamic balance and gait performance over compliant flooring among end users as a lot of previous research was performed with young, healthy participants [82,133,164]. More testing should be performed with equipment and tasks that may pose workplace safety concerns for care staff to ensure that compliant flooring is implemented in ways that protect the safety of everyone exposed, not just residents.

Overall, we found the symposium format was useful for engaging with stakeholders. Attendees were satisfied with the format and found it to be valuable for the following reasons: relevance to their current work, meeting colleagues and exchanging information, ease of understanding material presented, and the quality of discussion and dialogue during the symposium.

5.4.1. Limitations

We used a novel approach to explore the perceptions of key stakeholders about implementing compliant flooring in LTC. While we included stakeholders from different professional backgrounds, some stakeholder groups (e.g., LTC) were better represented than other groups (e.g., acute care). Attendees were invited from our existing networks and, therefore, may have different perceptions than those from other regions of the country, and may not hold the same views as stakeholders in similar roles from other countries. Moreover, the symposium does not directly address the perspectives of LTC residents and their families, an important stakeholder group for the successful implementation of compliant flooring in LTC. Future research would benefit from partnering with these groups. Though our small sample size afforded meaningful engagement from all attendees during the workshop, it precluded the ability to stratify the results by subgroup. Finally, our approach focused on implementing compliant flooring within LTC. Therefore, the results may not translate directly to other settings, such as the community or acute care, though similar methods could be used to explore advantages, disadvantages, and research gaps in those settings.

5.4.2. Conclusion

In conclusion, attendees identified key advantages and disadvantages of implementing compliant flooring, as well as important gaps in evidence about compliant flooring that should be prioritized by future studies. By attending the workshop, attendees gained awareness about compliant flooring systems for preventing fall-related injuries among residents and an understanding of the evidence supporting its use as a technology to prevent fall-related injuries. We anticipate that the results of this symposium will facilitate future research projects that expand knowledge on compliant flooring for injury prevention.

Chapter 6. Discussion

6.1. Summary of thesis

Fall-related injuries can have serious consequences for older adults, including increased risk for dependence in daily activities and mortality. The LTC setting is a particularly high-risk environment for falls and fall-related injuries with rates 2-3 times higher than for community-dwelling older adults [15–19]. Compliant flooring is a novel intervention strategy that aims to reduce the incidence and severity of fall-related injuries to improve health outcomes for older adults, including LTC residents, who have sustained a fall. However, a lack of synthesized evidence about its feasibility in the LTC setting may be limiting widespread uptake.

My thesis used four different methodological approaches to conduct a comprehensive evaluation of compliant flooring to determine its feasibility for fall injury prevention for older adults residing in LTC. For compliant flooring to be considered a feasible intervention, stakeholders responsible for fall injury prevention in LTC would be enthusiastic about the proposed intervention and could potentially champion the implementation of compliant flooring if the randomized controlled trial data showed it to be clinically and cost effective, and if installations of compliant flooring would not harm LTC staff. By using different methods, I was able to determine the current state of the evidence by conducting a scoping review; produce new knowledge through an ergonomic evaluation; and use qualitative methods and knowledge translation strategies to uncover perceptions from key stakeholders. In this section, I summarize the main findings of my research, discuss common findings, limitations, and future directions identified across studies, and discuss how my findings contribute to our knowledge base on fall-related injuries in older adults.

In my first study (Chapter 2), I conducted a scoping review to determine what is presented in the literature about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems that aim to prevent fall-related injuries in health care settings. This review was considered a knowledge synthesis piece, which is part of the knowledge creation component of the KTA cycle (**Figure 1.1**), and responds to the information needs of health care decision makers tasked with preventing fall-related injuries. After screening 3611 titles and abstracts and 166 full-text articles, I included 84 records plus 56 companion (supplementary) reports. My review suggests that compliant flooring is a promising strategy for preventing fall-related injuries from a biomechanical perspective. However, I found that additional research is warranted to confirm whether compliant flooring (i) prevents fall-related injuries in real-world settings, (ii) is a cost-effective intervention strategy, and (iii) can be installed without negatively impacting workplace safety.

My scoping review identified that maneuvering floor-based lifts on compliant flooring may expose LTC staff to potentially injurious forces, which would pose an important barrier to the uptake of compliant flooring in LTC. For that reason, I examined whether a motorized floor-based lift would offset the effects of flooring on pushing forces for LTC staff. Specifically, Chapter 3 describes the effects of flooring type and resident weight on external hand forces required to push floor-based lifts in LTC. This study was considered a knowledge inquiry piece, which is part of the knowledge creation component of the KTA cycle (**Figure 1.1**). Fourteen female LTC staff performed straight-line pushes with two floor-based lifts (conventional, motor-driven), loaded with passengers of average and 90th percentile resident weights, over four flooring systems (concrete+vinyl, compliant+vinyl, concrete+carpet, compliant+carpet). My findings suggest that compliant flooring increased initial and sustained push forces and subjective ratings compared to concrete flooring. Compared to the conventional lift, the motor-driven lift substantially reduced initial and sustained push forces and perceived difficulty of pushing for all four floors and both resident weights. Participants exerted forces above published tolerance limits only when using the conventional lift on the carpet conditions (concrete+carpet, compliant+carpet). With the motor-driven lift only, resident weight did not affect push forces. Compliant flooring increased linear push forces generated by LTC staff using floor-based lifts, but forces did not exceed tolerance limits when pushing over compliant+vinyl. The motor-driven lift substantially reduced push forces compared to the conventional lift.

These findings may help to address risk of work-related musculoskeletal injury, especially in locations with compliant flooring.

Chapters 4 and 5 examined the barriers to and facilitators of implementing compliant flooring in LTC as perceived by key stakeholders involved in LTC fall injury prevention efforts. Informed by the findings of Chapters 2 and 3, I first adapted the current knowledge to local context by means of a brief script to inform 18 LTC senior managers about compliant flooring and then conducted interviews that explored barriers and facilitators to adoption of compliant flooring as a fall injury prevention strategy within LTC from the perspective these stakeholders (Chapter 4; action cycle of KTA Framework; **Figure 1.1**). Analysis of the interview data revealed three key themes emerged about compliant flooring: organizational facilitators to adoption of compliant flooring, organizational barriers to adoption of compliant flooring, and general considerations about compliant flooring. By seeking input from LTC senior managers, my findings provide evidence about important facilitators and barriers that stakeholders consider in deciding to install compliant flooring in LTC, such as injury prevention, effects to LTC frontline staff, financial considerations, and LTC staff's openness (of lack of) to change. My findings also suggest an opportunity for further knowledge translation and dissemination efforts to inform LTC senior managers about the currently available evidence on compliant flooring.

In Chapter 5, I adapted the knowledge acquired from Chapters 2 through 4 to the local context by organizing a series of podium presentations to inform 23 knowledge users from health care, industry, and research about compliant flooring (action cycle of KTA Framework; **Figure 1.1**). I then conducted a workshop to solicit the barriers to and facilitators of implementing compliant flooring in LTC as perceived by this broad range of stakeholders involved in LTC fall injury prevention efforts. Attendees believed the most important advantage of implementing compliant flooring was reducing the likelihood of injury in residents who have sustained a fall. The most significant disadvantage for attendees, representing a barrier to adoption, was cost. Attendees indicated a need for additional research, especially examining cost-effectiveness and clinical effectiveness. In conclusion, while stakeholders perceive compliant flooring to add value to LTC, there also remain significant informational and financial barriers to the uptake of compliant flooring.

6.2. Common findings across studies

Though I used a different methodological approach for each study, the findings from each chapter have some important commonalities. For instance, the scoping review (Chapter 2) provided some preliminary, but not conclusive, evidence of injury reduction (incidence and severity) after the installation of compliant flooring, but also indicated that compliant flooring may increase the risk of falling. This may be a result of the lack of published randomized controlled trials that were powered to test the clinical effectiveness of compliant flooring. My review suggested that future clinical effectiveness studies should use more rigorous methods, such as blinded, randomized controlled trials with sufficient sample sizes and follow-up periods to provide adequately powered and conclusive results. Participants from both the interview study (Chapter 4) and stakeholder symposium (Chapter 5) identified their number one facilitator/advantage of implementing compliant flooring as the potential for reducing injuries for LTC residents; however, both participant groups identified the need for more clinical research. It was noted, however, that some of the interview participants' uncertainties could be partially answered with existing, published papers, and only some interview participants believed there was a lack of research evidence. This suggested that participants may believe the evidence is available, but they may not know how to obtain this information. Therefore, these findings suggest an opportunity for further knowledge translation and dissemination efforts to inform LTC senior managers about the currently available evidence on compliant flooring.

The scoping review (Chapter 2) provided preliminary indications that compliant flooring may be a cost-effective strategy for health care systems with older adults at risk for falling. However, most of the cost-effectiveness studies were based on cost savings from hip fractures only. This highlights the need for more research that includes other injuries (e.g., head injuries, all fractures) in cost model. Moreover, financial considerations were an important subtheme for both the interview study (Chapter 4) and stakeholder symposium (Chapter 5). Though both studies highlighted that the flooring may reduce health care costs (via reduction of hospitalizations, surgeries, invasive procedures, etc.), there was more concern about the cost (i.e., cost of flooring, installation, maintenance, additional equipment costs) and how the flooring will be paid for (i.e., who would provide the funding? How will the cost be justified?). Symposium attendees strongly emphasized the need to conduct additional cost-benefit and/or cost-effectiveness analyses to help determine whether compliant flooring should be installed in LTC.

Furthermore, Chapters 2, 4, and 5 indicated that compliant flooring may provide benefits for care staff if compliant flooring was implemented in LTC. Unfortunately, these benefits were muted by the overwhelming concern about compliant flooring causing repercussions for LTC staff. Thus, I dedicated Chapter 3 to determine the effects of flooring system and resident weight on the external hand forces required for LTC staff to push floor-based lifts. In addition, I examined a motor-driven floor-based lift as a potential solution for LTC staff who are tasked with using floor-based lifts to mobilize LTC residents. Thus, Chapter 3 directly addressed one of the scoping review's recommendation of identifying and examining potential solutions to the identified concerns of maneuvering equipment over compliant flooring. However, Chapter 3 examined only one potential solution for floor-based lifts, and did not consider other rolling equipment. Moreover, participants from the interview study identified the potential negative effects to LTC staff as their biggest barrier of implementing compliant flooring. Participants also voiced uncertainty about how well LTC staff would accept compliant flooring and how it may affect the staff's ability to use equipment over compliant flooring, without increasing their risk of injury. This was further emphasized at the stakeholder symposium whereby attendees expressed similar concerns about implementing compliant flooring in LTC.

6.3. Future directions of compliant flooring research

By exploring a novel intervention (i.e., compliant flooring), each chapter provided a comprehensive list of suggestions for future research. To provide a business case, compliant flooring must address the problem it aims to address (i.e., fall-related injuries) while not costing more to install than the reduction it provides in health care costs (cost-effectiveness) or introducing additional repercussions (i.e., workplace safety). In addition, it is reasonable that participants from the interview study and stakeholder symposium believed there are still many uncertainties/unknowns about implementing compliant flooring. Compliant flooring is considered a novel intervention, when compared to other fall-injury prevention strategies; thus, there is still a need to conduct more research to provide more conclusive evidence about compliant flooring and such research should focus on providing additional evidence about clinical effectiveness, cost-effectiveness, and workplace safety of LTC staff. Moreover, Chapter 4 highlighted an opportunity to disseminate knowledge about the existing compliant flooring research via a communication strategy (e.g., education session) to inform LTC senior managers who were not included in the study. From my thesis work, I will partially address this by further disseminating my thesis findings to a range of stakeholders across Canada by hosting a webinar in partnership with the Canadian Agency for Drugs and Technology, publishing my results in open-access journals, and producing an Executive Summary and a 1-page Policy Brief.

Ultimately, the need to establish clinical efficacy is paramount over all other areas of research, as there is no reason to adopt compliant flooring if it does not fulfill its purpose of preventing fall-related injuries among older adults. Thus, the priority of future compliant flooring research should involve randomized controlled trials of residents in LTC that are adequately powered to determine if compliant flooring is effective at reducing serious fall-related injuries.

6.4. Limitations of thesis

There are a few known limitations to the research discussed in this thesis. First, all participants from Chapters 3, 4, and over 60% of Chapter 5 worked under the jurisdiction of Fraser Health Authority. Therefore, the results may not be generalizable to LTC staff (Chapter 3), LTC senior managers (Chapter 4) or other important stakeholders (Chapter 5) working in other parts of Canada or other countries. Fraser Health Authority has a renowned fall and injury prevention program and strives for their LTC sites to be proactive at implementing fall and injury prevention strategies. Therefore, the participants I interviewed in Chapter 4, for example, may have a stronger desire to implement new strategies for preventing fall-related injuries than locations with less support for injury prevention initiatives. Second, the results from the scoping review (Chapter 2) and ergonomics study (Chapter 3) were based on the specific flooring types used in each study, and therefore, may not be generalizable to other floors. In addition, Chapters 4 and 5 discuss compliant flooring as a general term, even though compliant flooring includes many different types of systems and brands. However, certain compliant flooring systems can perform better than others on specific outcomes (e.g., balance, gait performance, force requirements to maneuver equipment). This thesis does not suggest one or more specific types or brands of compliant flooring that are more feasible than other brands in LTC.

6.5. Implications of thesis

Despite these limitations, my thesis has important implications for the future of fall injury prevention among older adults. I conducted the first scoping review that synthesized the available evidence about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems that aim to prevent fall-related injuries. The review also identified gaps in evidence and new avenues for research. I included research from all disciplines that examine compliant flooring enabling me to provide a truly comprehensive summary of the existing research. In the short term, this should increase awareness of compliant flooring within and across disciplines. In the long-term, the study will help support decisions related to fall injury prevention in LTC and other health settings (e.g., acute care, home care, assisted living) and inform the design of safer environments for vulnerable older adults. Next, I conducted the first experiment of compliant flooring that tested a novel motor-driven floor-based lift and determined it reduces the push forces required for LTC staff to maneuver LTC residents compared to a conventional lift. This study also provided new knowledge that compliant flooring increased initial and sustained push forces and subjective ratings compared to concrete flooring. An important contribution of this study is that the motor-driven lift substantially reduces forces and may help to address risk of work-related musculoskeletal injury, especially in locations with compliant flooring.

The findings from the interview study and the stakeholder symposium support the importance of seeking input from stakeholders about the feasibility of compliant flooring before clinical and cost-effectiveness has been established. Both studies provided evidence about important factors (i.e., facilitators/advantages, barriers/disadvantages, research gaps) that stakeholders consider in deciding to install compliant flooring in LTC, such as injury prevention (Chapters 4 and 5), effects to LTC frontline staff (Chapters 4 and 5), financial considerations (Chapters 4 and 5), LTC staff's openness (or resistance) to change (Chapter 4), and installing in a new building instead of renovating an existing building (Chapter 5). In addition, by including an early-stage knowledge translation component, my thesis also adds to a small body of knowledge translation literature in LTC. Knowledge translation studies in LTC have primarily focused on knowledge translation interventions after efficacy was established [109]. I believe that conducting early-stage knowledge translation, in tandem with the conduct of clinical and cost-effectiveness trials, will improve future dissemination of trial findings and implementation of compliant flooring, if appropriate, and improve the design of future trials. Moreover, by using an integrative knowledge translation approach throughout my thesis[102], the findings are more relevant to, and thus more likely to be useful to, decision makers involved in fall injury prevention.

Although my studies revealed some challenges to the adoption of compliant flooring, I did not uncover barriers that are serious enough to stop exploring compliant flooring as an injury prevention strategy in LTC. I believe compliant flooring is feasible as the stakeholders that I involved in my thesis were generally enthusiastic about the proposed intervention and could potentially champion the implementation of compliant flooring if compliant flooring is found to be clinically and cost-effective, and if installations of compliant flooring would not harm LTC staff. Overall, my thesis provided a unique, multimethod approach to investigating a novel health care intervention. This model of early-stage and integrated knowledge translation could be used as a model for other researchers aiming to increase knowledge uptake efforts within LTC.

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Appendix A

Final Ovid MEDLINE search strategy from Chapter 2

Table A1 Final Ovid MEDLINE Search

Syntax Line	Search Term
1	floor*.mp
2	carpet*.mp
3	ground surface*.mp
4	smartcell*.mp
5	tarkett omnisports excel.mp
6	softile.mp
7	sorbashock.mp
8	forbo.mp
9	kradal.mp
10	noraplan.mp
11	Floors and Floorcoverings/
12	or/1-11
13	force*.mp
14	impact*.mp
15	trauma*.mp
16	biomechanic*.mp
17	compress* strength*.mp
18	strain*.mp
19	load*.mp
20	acceleration*.mp
21	mechanical stress*.mp
22	Biomechanical Phenomena/
23	Compressive Strength/
24	Stress, Mechanical/
25	or/13-24
26	balanc*.mp
27	postur*.mp
28	stabilit*.mp
29	postural sway.mp
30	bod* sway.mp
31	foot displacement*.mp
32	foot deflection*.mp

33	gait*.mp
34	walk*.mp
35	locomotion*.mp
36	perturbation*.mp
37	mobil*.mp
38	toe clearance*.mp
39	centre of pressure*.mp
40	center of pressure*.mp
41	senior*.mp
42	elder*.mp
43	older adult*.mp
44	older*.mp
45	geriatric*.mp
46	old age*.mp
47	aging*.mp
48	gerontology.mp
49	Postural Balance/
50	Posture/
51	Gait//
52	Locomotion/
53	exp "Aged"/
54	exp Geriatrics/
55	or/26-54
56	injur*.mp
57	wound*.mp
58	trauma*.mp
59	bruise*.mp
60	bruising*.mp
61	contusion*.mp
62	swell*.mp
63	hematoma*.mp
64	haematoma*.mp
65	laceration*.mp
66	abrasion*.mp
67	cut*.mp
68	sprain*.mp
69	strain*.mp
70	dislocation*.mp
71	fractur*.mp
72	concussion*.mp

73	intracranial haemorrhage*.mp
74	intracranial hemorrhage*.mp
75	Wounds and Injuries/
76	Injury Severity Score/
77	Contusions/
78	exp "Dislocations"/
79	Lacerations/
80	Soft Tissue Injuries/
81	Multiple Trauma/
82	exp "Fractures, Bone"/
83	Neck Injuries/
84	Back Injuries/
85	exp "Arm Injuries"/
86	exp "Hand Injuries"/
87	exp "Hip Injuries"/
88	exp "Leg Injuries"/
89	exp "Trauma Severity Indices"/
90	exp "Wounds, Nonpenetrating"/
91	exp "Brain Injuries"/
92	Sprains and Strains/
93	Athletic Injuries/
95	or/56-93
95	cost*.mp
96	health resource*.mp
97	resource allocation*.mp
98	economic*.mp
99	expens*.mp
100	exp "Costs and Cost Analysis/"
101	Health Resources/
102	Economics/
103	exp "Economics, Medical"/
104	exp "Economics, Hospital"/
105	exp "Resource Allocation"/
106	or/95-105
107	25 OR 55 OR 94 OR 106
108	fall.mp OR falls.mp OR fell.mp OR faller*.mp OR falling.mp
109	trip.mp OR trips.mp OR tripped.mp OR tripping.mp
110	slip.mp OR slips.mp OR slipped.mp OR slipping.mp
111	Accidental Falls/
112	or/108-111

113	107 AND 112
114	injur*.mp
115	wound*.mp
116	chronic pain.mp
117	muscle pain.mp
118	musculoskeletal pain.mp
119	rotator cuff.mp
120	bursitis.mp
121	dislocation*.mp
122	shoulder impingement syndrome*.mp
123	overuse syndrome*.mp
124	sprain*.mp
125	strain*.mp
126	human engineering.mp
127	occupational exposure*.mp
128	lifting.mp
129	push*.mp
130	pull*.mp
131	occupational accident*.mp
132	ergonomic*.mp
133	manual handling.mp
134	patient handling.mp
135	biomechanical phenomena.mp
136	occupational health.mp
137	fatigue*.mp
138	Wounds and Injuries/
139	Musculoskeletal Pain/
140	exp "Tendon Injuries"/
141	exp "Bursitis/"
142	exp "Sprains and Strains"/
143	exp "Dislocations"/
144	Neck Pain/
145	Shoulder Pain/
146	Rotator Cuff/
147	Shoulder Impingement Syndrome/
148	exp "Arm Injuries"/
149	exp "Hand Injuries"/
150	Back Pain/
151	Low Back Pain/
152	Back Injuries/

153	Soft Tissue Injuries/
154	Human Engineering/
155	Moving and Lifting Patients/
156	Lifting/
157	Biomechanical Phenomena/
158	Occupational Exposure/
159	Occupational Health/
160	Occupational Injuries/
161	Fatigue/
162	Muscle Fatigue/
163	Cumulative Trauma Disorder/
164	Musculoskeletal Physiological Phenomena/
165	or/114-164
166	health personnel.mp
167	physical therapist*.mp
168	physical therapist* assistant*.mp
169	caregiver*.mp
170	medical staff*.mp
171	nurse*.mp
172	nurs* staff*.mp
173	nurs* aide*.mp
174	community health worker*.mp
175	Health Personnel/
176	Physical Therapists"/
177	Physical Therapist Assistants/
178	Caregivers/
179	exp "Medical Staff"/
180	exp"Nurses"/
181	exp "Nursing Staff"/
182	Nurses' Aides/
183	Community Health Workers/
184	or/166-183
185	165 AND 184
186	113 OR 185
187	12 AND 186
188	animals/ not humans/
189	187 NOT 188

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Appendix C

Supplementary table from Chapter 3

Characteristics of floor-based lifts

Table A2 Characteristics of floor-based lifts

	Conventional Floor-Based Lift	Motor-Driven Floor-Based Lift
Manufacturer	ArjoHuntLeigh	Indes
Brand	Arjo Sara 3000	esense Rise
Capacity (kg)	200.0	200.0
Measures (*L* x *W*) (cm)	103.5 x 64.0	100.0 x 62.0
Net mass (kg)	62.0	76.5
Orientation pushbar	horizontal/vertical	horizontal/vertical
Orientation handle height (cm)	free (101.0 - 115.0)	free (91.0 - 119.0)
Instrumented handle height (cm)	101.0	119.0
Handle width (cm)	fixed (155.0)	fixed (108.0)
Castor diameter (cm)	7.0 (front); 12.0 (back)	9.5 (front); 12.0 (back)
Castor width (cm)	2.5 x 2 (front); 3.0 (back)	7.5 (front); 8.5 (back)
Castor design	4 castors	4 castors and motorized wheel in the centre

Appendix D

Supplementary results from Chapter 3

Forward initial and sustained forces

Flooring system x lift type interaction

We observed an interaction between flooring system and lift type on mean F_{init_fwd} ($p < .001$) and F_{sust_fwd} ($p < .001$). Independent of resident weight, mean forces were lower for the motor-driven lift than the conventional lift on all flooring conditions (by 27.3 to 73.7 N for initial forces and by 12.1 to 62.4 N for sustained forces). With the vinyl overlay, F_{init_fwd} was 49.0 N higher (SE = 4.2 N, $p < .001$, 59.6% increase) on the compliant than the concrete floor when pushing the conventional lift. Similarly, F_{init_fwd} was 30.2 N higher (SE = 4.2 N, $p < .001$, 50.3% increase) on the compliant than the concrete floor when pushing the motor-driven lift. With the carpet overlay, F_{init_fwd} was 22.3 N higher (SE = 4.3 N, $p < .001$, 14.6% increase) on the compliant than the concrete floor when using the conventional lift. With the carpet overlay, there was no differences in F_{init_fwd} ($p = .375$) between compliant and concrete floors when pushing the motor-driven lift.

Similar trends were observed for the sustained forces (F_{sust_fwd}). With the vinyl overlay, F_{sust_fwd} was 46.1 N higher (SE = 1.7 N, $p < .001$, 190.5% increase) on the compliant floor than the concrete floor when pushing the conventional lift and 13.3 N higher (SE = 1.7 N, $p < .001$, 82.2% increase) when pushing the motor-driven lift. With the carpet overlay, F_{sust_fwd} was 16.8 N higher (SE = 1.7 N, $p < .001$, 21.4% increase) on the compliant than the concrete floor when pushing the conventional lift. With the carpet overlay, there was no differences in F_{sust_fwd} ($p = .097$) between compliant and concrete floor when pushing the motor-driven lift.

Resident weight x lift type interaction

We observed an interaction between resident weight and lift type on F_{init_fwd} (p = .003) and F_{sust_fwd} (p < .001). Independent of flooring system, F_{init_fwd} was 19.0 N higher (SE = 3.0 N, p < .001, 14.6% increase) and F_{sust_fwd} was 13.3 N higher (SE = 1.2 N, p < .001, 22.6% increase) for the 90th percentile weight than the average weight when pushing the conventional lift. In contrast, there were no differences in F_{init_fwd} (p = .168) between the average and 90th percentile weight conditions when pushing the motor-driven lift, but mean F_{sust_fwd} was 3.2 N higher (SE = 1.2 N, 13.6% increase, p = .037) when pushing the 90th percentile versus average weight.

When pushing the motor-driven lift, F_{init_fwd} was lower by 45.5 N (SE = 3.0 N, p < .001, 30.3% decrease) with the average resident weight and 58.3 N lower (SE = 3.0 N, p < .001, 32.5% decrease) with the 90th percentile resident weights compared to the conventional lift. The motor-driven lift reduced F_{sust_fwd} by 37.4 N (SE = 1.2 N, p < .001, 51.6% decrease) when pushing the average weight and F_{sust_fwd} by 47.5 N (SE = 1.2 N, p < .001, 56.2% decrease) when pushing the 90th percentile weight compared to the conventional lift.

Flooring system x resident weight interaction

An interaction between flooring system and resident weight was observed for F_{sust_fwd} (p = .019). Independent of lift type, F_{sust_fwd} was higher when pushing the 90th percentile weight than the average weight by 8.2 N (SE = 1.7 N, p < .001, 15.1% increase) on compliant+vinyl floor, 8.3 N higher (SE = 1.7 N, p < .001, 14.7% increase) on concrete+carpet floor, and 12.0 N higher (SE = 1.7 N, p < .001, 18.2% increase) on compliant+carpet floor. There was no difference, however, in F_{sust_fwd} when pushing the average and 90th percentile weight conditions over the concrete+vinyl floor (p = .130).

Independent of lift type, F_{sust_fwd} was higher when pushing over compliant floor conditions compared to their comparative concrete floor conditions. Specifically, F_{sust_fwd} was 27.9 N higher (SE = 1.7 N, p < .001, 144.3% increase) for compliant+vinyl floor when pushing average resident weight and 31.5 N higher (SE = 1.7 N, p < .001, 128.4%

increase) when pushing 90th percentile resident weight compared to concrete+vinyl floor. Additionally, F_{sust_fwd} was 8.9 N higher (SE = 1.7 N, $p < .001$, 16.8% increase) for concrete+carpet floor when pushing average resident weight and 12.6 N higher (SE = 1.7 N, $p < .001$, 20.0% increase) when pushing 90th percentile resident weight compared to compliant+carpet floor.

Downward initial and sustained forces

Initial forces

We observed a main effect for flooring system ($p < .001$) and lift type ($p < .001$) on F_{init_dwn}, and no interaction between flooring system and lift type on F_{init_dwn} ($p = .786$). There was no main effect for resident weight ($p = .104$). Note, we do not report mean percent changes between conditions in initial downward forces because of high variability. Independent of lift type and resident weight, F_{init_dwn} was highest for concrete+vinyl (22.7 N) followed by compliant+vinyl (16.7 N), concrete+carpet (7.2 N), and compliant+carpet (-2.3 N). There was no difference in F_{init_dwn} when pushing the lifts over concrete+vinyl compared to compliant+vinyl ($p = .259$). With the carpet overlay, F_{init_dwn} was 9.5 N higher (SE = 3.3 N, $p = .022$) on the concrete+carpet floor compared to compliant+carpet floor. Independent of flooring system and resident weight, F_{init_dwn} was higher when using the conventional lift (24.7 N) versus the motor-driven lift (-2.6 N, $p < .001$).

Sustained forces

We observed a significant interaction between flooring system and lift type on F_{sust_dwn} ($p < .001$). There was no main effect for resident weight ($p = .411$). Independent of resident weight, push forces were lower by 7.5 to 21.4 N when pushing the motor-driven lift versus the conventional lift on all flooring conditions. With the vinyl overlay, F_{sust_dwn} was 7.2 N (SE = 2.2 N, $p = .023$, 21.5% increase) higher on compliant than concrete floor when pushing the conventional lift, but there were no differences between compliant and concrete floor pushing the motor-driven lift ($p = .948$). With the carpet overlay, there were no differences in F_{sust_dwn} between compliant and concrete floor when pushing the conventional ($p = .977$) or motor-driven lift ($p = .760$).

Appendix E

Examples of coding scheme from Chapter 4

Table A3 Examples of the coding scheme used in data analysis for all subthemes

Subtheme	Description of Subtheme Code	Examples from Participants
Under facilitator theme		
Injury prevention	- Reduced # of injuries (serious, minor) - Reduces severity - Reduced acute care visits, surgeries, invasive procedures - Superior at injury reduction compared to other fall injury interventions (e.g., hip protectors)	*"Definitely because then, you know, they can actually fall anywhere. It doesn't have to be in that square [fall mat surface area] because we have residents who can actually walk a few steps. They already walk past the floor mat before they fell. So that's certainly an area that if the whole room is protected, for sure that would be actually helpful." –Emma* *"If it helps my residents have less injuries and have a detrimental outcome from the fall, then yeah. And I think the population is aging, and we're living longer. So these are the things that we have to look at." – Elizabeth*
LTC staff's openness to change	- Front-line staff (e.g., open to change) - Management (e.g., CEO supportive of injury prevention interventions)	*"The CEO [Chief Executive Officer] actually has a great vision of fall management." – Emma* *"I think if they [LTC staff] knew the benefits as far as for decreased injury as well as for themselves, as far as the fatigue factor, then yeah, there'd definitely be buy-in. Would be definitely buy-in." –Michaela*

Financial considerations – funding availability and cost savings	- Access to funding - Increased funding from health authority - Reduced costs (health care) - Reduced purchasing of less desirable equipment (e.g., falls mats) - probe: if provided for free	*CCL: If we were to give it to you for free, would that eliminate that barrier of cost? Would you--* *Olivia: Of course. Or if we can find other ways of funding.*
Benefits to LTC frontline staff	- Improved walking comfort - Passive intervention (i.e., less work for staff vs. other prevention strategies) - Improved morale	*Maya: So I think anything that we can do-- and it's also interesting from a staff perspective watching staff when somebody has fallen and seeing their faces. Because you see somebody-- and all of us do the same thing. It's like [inaudible, voices overlap]--* *CCL: The gasp, yeah.* *Maya: -- and-- but when you see that person fall, we all do the same thing. And it affects people, especially, you know, if you see a rotated hip and the leg's rotated and all of that. So it's just-- anything we can do to reduce that [installing compliant flooring], I think, is a fantastic.*
Implementation in a new build (versus retrofit)	- Ease of implementing in a new build vs. renovations/retrofitting existing care home	*"But if you're building a new home and you're-- most of the ways people build new homes these days are by way of RFP's [Request for Proposals] to the health authority, put out a request for proposals and you might have-- so when we-- for our new building we had to start with about 40 proposals to Fraser Health to rebuild and they whittled it down. It was a competitive process. They whittled it down to-- I think three or four got new building. So in that, if you build it into your budget when you're presenting that proposal, then that's probably the best opportunity to do it. And then sell the health authority on your building might cost more than your competitor's, but the health authority is going to save money in the long run because less of the clients in that building are going to be going into the acute care system." –Jake*
Improved flooring performance	- Noise reduction - Hygienic - Ease of maintenance	*"I think it-- one thing is-- 'cause to compare with the carpet, it's easy to keep clean. That's one thing." –Ella*

		"No, just secondary, the sounding – sound barrier too which is quite nice." –Abby
Improved perceptions of care home	- Innovative - Forward thinking	*"Yeah, I think by having-- just by having it, you up the discussions about it, and it becomes more out there. So you've got this flooring in your building. People talk about it. So I think your safety awareness goes up, and your prevention goes up. Like, people that take first aid training, their safety awareness and culture increases, right, just 'cause they have that knowledge. So I think by having it…"–Abby*
Increased resident mobility	- Easier to walk on - Reduced tripping risk (vs. falls mats)	"*We were talking about fall mats, I think, and-- 'cause there's always a tripping hazard with fall mats. So just having everything that's on one surface, be so much better." –Audrey*
Under barrier theme		
Negative effects to LTC frontline staff	- Ergonomics – increased use of ceiling lift - Ergonomics - difficulty moving equipment (e.g., wheelchairs, floor-based lift)	*"Well, the big, big concern for me is that, you know, the lifts. Pushing. Because I don't really—I'm fan of not injuring anybody's self. Like, my main staff is supposed to be all the time safe." –Audrey*
Financial considerations – cost and lack of funding	- Availability of funding for flooring - Cost of flooring (materials, implementation - Availability of funding for equipment	*"Yeah, because you'd have to look at the flooring. Then you'd have to look at where it's going and then if you have to look at the motorized lifts and what else you would have to -- for different equipment to accommodate the flooring. 'Cause it's not just the flooring. And training for the staff on proper body mechanics. You have to-- it's a whole big-- it's not just how much the flooring costs. So there's no way that I could even answer that [whether I would install compliant flooring] at this time because there's more costs that would be involved." –Abby* *"The two disadvantages I would see is obviously cost. Cost associated with the initial install. That would be the only issue. And of course maintenance costs of cleaning it and maintaining it. And my only other concern really is the effect of heavy equipment on the floor." –Harrison* *"And also the cost. It's not cheap. The cost is very expensive. Even the floor mat, right, and if you actually go out and buy the Span one, it's 200-and-something dollars. And to buy*

		the SmartCell, it's 400-- the rep[resentative] was telling us it's 400-and-something, I can't remember." –Emma
Lack of research evidence	- Lack of Conclusive Evidence - Injury Prevention - Lack of Conclusive Evidence - Durability/Hygiene	*Laurel: I'm on the leery end. So I'm in between - CCL: And I guess why, I guess, is it, because you need more information. Laurel: So I'm The concerns-- yeah, absolutely. I would need to know more about how it's going-- like, even this one site, what is the population like? Are you receiving-- do they have the complex residents that we have? So I'd want to see it at more than one site. I know one site's trying it, that's great. But I would want to see at another site before I felt comfortable that was more, like, perhaps closer to what our typical sites are looking at. I mean, you're looking at sites with minimum 125 residents now or 120 is-- yeah, around that number. So if it was done at a smaller site it would be, like, well, oh, I don't know.* *"Yes. And then of course that 30-year lasting [floor] would break down because of the usage and what's happening to the flooring." –Abby*
Installation challenges	- Logistics (e.g., moving resident, length of renovations) - Accommodating existing building design	*"…a challenge because this facility was not built to have those kind of flooring. So when that was put in, the outside hall and the room, there is a little bit of an elevated surface. So then it's a tripping hazard for the staff." –Emma*
Resident mobility challenges	- Increased ceiling lift use (interaction with ceiling lift use) - Difficulty with using (self-propelling wheelchair) - Falls risk	*"Right. And sit-to-stand [floor-based] lifts are used for residents who are still able to weight-bear. And so the idea is to maintain some independence for that individual and maintain some strength. Whereas if we go right to a ceiling lift and they don't need it, it's to the disadvantage of the resident. I would suggest exploring other companies." –Annalise*
LTC staff's resistance to change	- Front-line staff (e.g., resistance to change) - Management (e.g., CEO not supportive of injury prevention interventions)	*"And of course from the beginning of the physical year you can't add anything on until the budget you work on-- for the end of this year for next year. So even if we said, oh, this looks good, we won't be able to do it this*

	- Lack of flexibility with implementing new interventions	*year anyway. It all has to be-- the budget's always planned a year ahead." –Abby*
Under general concerns theme Uncertainties about clinical effectiveness	- Unknowns about its effectiveness at reducing injuries - Unknowns about the types of injuries being reduced - Uncertainties about certain populations benefitting more than others	*"But I haven't heard that it's reduced falls. I haven't really heard much about it after that. I haven't heard-- really heard that it was a good idea or a bad idea or did it help them reduce the fractures. I could ask next time I go to meeting," –Elizabeth* *"And that's how, I hate to say it, but, you know, everything in life is about trial and error, and this is already in place somewhere. So we would look at the success of the previous locations. No different-- we do that with all flooring." –Harrison* *"Has anybody actually think about-- you know in the playground for the kids, those kind of flooring is actually prevent injury from the kids falling off the jungle gyms, right? So what about those kind of flooring, those kind of material? What is that like?" –Emma*
Unknown effects for LTC staff	- Uncertainty of how well LTC will accept compliant flooring - Uncertainty about how it may affect the staff's ability to use equipment over compliant flooring	*"I think it probably is beneficial. Again, the carts and the-- moving lifts on it, that was one thing that we weren't sure about. And having furniture on it." –Mellie*
Uncertainties about flooring performance	- General inquiries about performance based factors (e.g., maintenance, cleaning, acoustics, hygiene, aesthetics, durability [e.g., compliant flooring interaction with furniture])	*"I'd be interesting to know if, over the long term, the product breaks down or becomes less effective over time." –Fitzgerald*
Uncertainties about funding availability and cost of implementation	- Uncertainties about funding availability - Uncertainties of how much it will cost to implement	*"But it is still contingent, to some degree, on the amount of funding that we have." –Olivia*
Uncertainties about LTC staff's openness to change	- Uncertainties about front line staff and management's openness to change	*"Give them [LTC frontline staff] ample warning [when implementing a new intervention]. Give them lots of information. I think bringing in people who've tried it and experienced it, firsthand feedback. Introduce it in small area-- one area at a time, for example, when I first started here I*

		introduced the ceiling lift, there was a lot of resistance-- put it in place and now they love it, they want more ceiling lifts. [laughs]" – Annalise
Uncertainties about how it will affect resident mobility	- Uncertainty about ease of walking and self-propelling wheelchair - Uncertainty about falls risk	*"Again, not knowing very much about the flooring, is there-- does it affect someone's walking in terms of sensation? We're so used to walking on a floor like this. Would it affect a resident's balance, perception and that? I don't know." – Annalise*
Unknowns about installation and retrofit	- General inquiries and uncertainties about the renovation process	*"But actually, if I present it to our management team and my CEO [Chief Executive Officer], I think they would be happy to try out another floor-- another room, to have that flooring. But I don't know how that would work here. And would it have a difference because now we're in the new building. Because before our room is sagging. The floor is not on the nice [inaudible], like, it's wonky, the flooring." – Daria*
Unknowns of marketing compliant flooring to recruit residents	- Uncertainties of marketing compliant flooring to recruit residents	*CCL: So you wouldn't necessarily entice people to come to your care home 'cause they don't really have the option.* *Fitzgerald: No, we have a huge-- long wait list.* *CCL: Like, you're always going to-- yeah.* *Fitzgerald: If we were, like, a private-- people have to pay privately, perhaps that might be an enticing feature.*

Note. All names mentioned in table are pseudonyms to respect the confidentiality of the participants.