Video Analysis of the Circumstances of Falls in Long-term Care

by

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Abstract

Falls cause more than 95% of hip fractures and 65% of head injuries in older adults. A major barrier to prevention is lack of objective evidence of the circumstances of falls, especially in the high-risk long-term care (LTC) setting. My PhD research addresses this issue through the analysis of falls captured on video in two LTC facilities. My first study involved the development and validation of a 24-item video analysis questionnaire that probes key biomechanical aspects of fall initiation, descent, and impact from video footage. My results demonstrated good inter-rater and intra-rater reliability in 17 of the 24 questions (agreement≥80%, kappa≥0.6). My second study compared the circumstances of falls described in incident reports to information from video analysis (n=309, with 863 falls). I found poor agreement on the cause of imbalance and activity at time of fall (agreement=45%, kappa≤0.25), and moderate agreement on the use of mobility aids (agreement=79.5%, kappa=0.59). My third study examined how risk of head impact during falls was associated with biomechanical factors (from video analysis) and physiological factors (from Minimum Data Set) (n=160, with 520 falls). I found that 33% of falls involved head impact. Odds for head impact were increased more than 2-fold for female, impaired vision, and intact cognition. These trends were explained in part by women and individuals with relatively intact cognition who tend to fall during walking and fall forward (both increased the odds for head impact). Odds for head impact were not reduced by hand impact. Body rotation during descent from forward to sideways or backward decreased the odds of head impact nearly 3-fold. My fourth study used the same data set to examine how risk of hip impact during falls was influenced by biomechanical and physiological factors. I found falling forward was just as likely as falling sideways to cause hip impact. There was no association between physiological factors and odds for hip impact. Collectively, my findings should help guide the development of improved fall and injury prevention strategies, by providing new evidence on the circumstances of falls in LTC, and the risk factors for impact to the head and hip.

Keywords: Video analysis of real-life falls, long-term care, fall mechanisms, Minimum Data Set, head impact, hip impact

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List of Acronyms

LTC	Long-term Care
FVAQ	Fall Video Analysis Questionnaire
MDS	Minimum Data Set

Chapter 1. Introduction

1.1. Epidemiology of falls in older adults

Falls and fall-related injuries are major concerns among older adults. About 30% of community-dwelling adults over the age of 65 and more than 50% of older adults residing in long-term care (LTC) facilities will fall each year [1]. Between 10-15% of falls cause serious injury, and 1-2% cause hip fractures [2]. There are approximately 28,000 annual cases of hip fracture in Canada, and more than 95% of these cases are resulting from falls in seniors [3, 4]. Over 25% of older adults who have experienced a hip fracture die within a year [5], and 50% suffer a major decline in independence such as difficulty in performing daily activities [6-8]. Furthermore, falls cause more than 65% of traumatic brain injury (TBI) in older adults [9, 10], and the hospital mortality in older adults with TBI is over 30% [11, 12]. Falls also cause over 90% of wrist fractures [13, 14] and a large proportion of shoulder, elbow, lower back, and spine injuries in older adults [15]. In addition to injuries, falls are associated with negative psychological consequences such as fear of falling, immobilization, and social isolation [16, 17], which decrease independence and quality of life. Falls bring not only suffering to older adults and their care providers, but also a huge economic cost to society. The direct costs associated with falls among older adults in Canada are estimated to be more than $2.0 billion annually [5, 15]. Clearly, developing improved strategies to decrease the incidence of falls and fall-related injuries in older adults is an essential health priority.

In LTC facilities, the rates of falls and fall-related injuries are 2–3 times higher than among community dwelling older adults [18, 19]. In addition, efforts to reduce falls and injuries have been less successful among older adults in LTC when compared to seniors living in the community. According to a 2013 Cochrane review [20], the results from both exercise interventions and multi-factorial interventions in LTC facilities were inconsistent and overall did not show a benefit in reducing rates and risk for falling. The only effective intervention identified by the review was vitamin D supplementation, which is associated with a 37% reduction in the rate of falls. The complex medical status of LTC residents, including the frequent co-existence of physical and cognitive impairment [21-24], may cause the mechanisms of falls to be fundamentally different than for healthier community dwelling older adults, necessitating different approaches to prevention.

1.2. Cause and circumstances of falls

A primary challenge to care providers in preventing falls is the diverse range of physiological and situational variables that contribute to falls, and the tendency for fallers to present with multiple co-existing risk factors [25]. A similarly important, but less recognized barrier to prevention is lack of objective evidence of the mechanisms of falls - “how” and “why” they occur. Falls are typically defined as “an unexpected event in which the individual comes to rest on the ground, floor, or lower level” [26]. Based on conceptual models presented by Hayes et al [27] and Noury et al [28], a fall can be divided into four distinct phases: (1) an instability phase that results in a loss of balance; (2) a descent phase after imbalance; (3) an impact phase; and (4) a post impact phase during which the individual comes to rest, and typically attempts to rise from the ground. Information related to the first three phases defines “how” the fall occurs.

1.2.1. Fall initiation

Hayes and colleagues defined fall initiation as an instability phase that results in a loss of balance [27] due to an uncorrected displacement of the centre of mass (COM) from the base of support (BOS) [29]. Numerous studies have examined intrinsic (physiological) and extrinsic (environmental or situational) risk factors for falls. Established intrinsic risk factors for falls include neurological diseases (e.g. Parkinson’s disease, stroke), cardiovascular dysfunction (e.g., orthostatic hypotension, syncope), use of psychotropic medications, cognitive impairment, lower extremity weakness, poor balance, and impaired vision [18, 30-36]. Extrinsic factors include environmental hazards such as tripping obstacles, clutter, slippery floors, floor transitions, and poor lighting [29, 37, 38]. Situational factors include the use of mobility aids at time of falling and the type of footwear at the time of falling [39-41]. However, classifications based on intrinsic and extrinsic causes have mainly focused on the risk factors for falls. Due to the complexity of multiple contributing factors, it is inadequate to describe a single factor that causes the fall in older adults.

Others have classified the causes of imbalance depending on the type of biomechanical perturbation proceeding the fall [42]: Under this scheme, a BOS perturbation refers to imbalance resulting from change in the position of the BOS (e.g., foot position), away from the position of the COM [42]. Examples include slips, trips or stumbles. In contrast, a COM perturbation refers to imbalance due to displacement of the COM outside the BOS. Examples include an externally applied push or collision (hit or bump), or a self-induced displacement during transferring, bending, reaching, or turning (incorrect weight shifting). A third category involves no obvious perturbation, but instead a transient physiological event that disrupts posture control mechanisms. Examples include sudden loss of consciousness or loss of muscle tone of the lower limbs (leg collapse). Previous studies have reported that about 50% of falls in community-dwelling older adults resulted from “trips or slips” [2, 35, 36], followed by “loss-of-balance,” “legs giving way,” “dizziness”, and “loss of support” [2, 43, 44]. Studies have also examined the activities at the time of falling in community-dwelling older adults, with the most commonly reported activities include walking (accounting for 50% to 70% of falls), rising up or sitting down, standing, turning, and sitting [1, 14, 29, 43, 44]. Few studies have examined the cause and activity related to falls in LTC, and they reported that most falls in LTC were associated with transferring from a bed, chair, or wheelchair [45, 46].

1.2.2. Fall descent

The descent stage of the fall commences just after fall initiation, and ends just before landing. The variables of interest include the initial direction of the fall, and attempts to recover balance or prepare for landing. Prospective cohort studies have shown that falling sideways increased the risk for hip fracture by approximately 6-fold [27, 47], and forward falls cause the greatest risk for wrist fracture [14]. While previous clinical studies have characterized falls as having only a single direction, laboratory experiments have shown that young participants often change the orientation of the fall during descent [48, 49]. This supports the importance of examining both the initial fall direction and landing configuration as potentially related but separate factors for fall direction.

Balance recovery (after the occurrence of imbalance) involves re-establishing the vertical projection of the COM within the boundaries of the BOS. Balance recovery strategies have been divided into two general classes: “fixed support” and “change in support” reactions [50]. In fixed support reactions, the feet remain stationary, and the COM is moved through muscle forces generating torques at the ankle and/or hip. [50]. “Change in support” reactions include stepping and reaching-to-grasp responses, and allow recovery from much larger perturbations (displacements of the COM outside the BOS), and are commonly evoked in both healthy young and older adults even at small perturbation levels [51, 52]. When compared to young adults, older adults tend to take multiple smaller steps to recover balance, as opposed to a single large step [53, 54], and following an initial forward or backward step, execute sideways steps to recover from lateral instability [50]. With regard to reaching responses, older adults are more likely than young adults to initiate arm movements and to grasp handrails for support following a postural perturbation [50, 55]. However, the speed at which these responses are initiated and executed is slower, in older than young adults [50].

1.2.3. Fall impact

The impact stage of the fall involves the body landing on the ground (or other objects), and absorbing the impact energy of the fall. The factors of interest include the primary orientation of the body at landing (forward, backward, or sideways) and the occurrence of contact to key body sites (e.g., head, shoulder, torso, pelvis, hands, and knees).

There are strong associations between impact to the head and risk for brain injury [56], while impact to the hip or wrist strongly influences risk for fracture at these locations [14]. The forces (and tissue stresses) generated during landing also depend on impact velocity, body mass, the type of object being impacted [57], and the timing of impacts to the various body parts. For example, impact to the hands has been found to decrease the odds of hip fracture 3-fold in clinical studies [14, 47], and in laboratory studies, hand impact or knee impact caused a reduction in the impact velocity of the pelvis [48].

1.3. Risk factors for injuries during falls

1.3.1. Risk factors for hip fracture

Although over 95% of hip fractures in older adults are caused by falls, only 1 – 2% of falls result in hip fracture [2-4]. Previous studies have identified a range of intrinsic risk factors for fall-related hip fractures in older adults. In general, these factors affect injury risk by decreasing the resistance of the bone to trauma (e.g., failure stress), increasing the frequency of falls, and/ or increasing the severity of impact to the hip during the fall (e.g., peak femoral neck stress during impact). Independent risk factors associated with hip fracture include lower limb dysfunction [13, 58], slow gait speed and impaired balance [59, 60], neurological disease such as Parkinson's syndrome and stroke [61-64], use of psychotropic medications [65, 66], poor vision [13, 60], and decreased bone mineral density [67, 68]. Declines in physical function (ability to independently perform activities of daily living) and mobility were also shown to increase the risk for hip fracture [47, 66, 69, 70], and cognitive impairment was found to associate with an approximate 2-fold increase for hip fracture [47, 71].

1.3.2. Fall mechanics and risk for hip fracture

Cummings and Nevitt [72] hypothesized that three conditions must be met for a fall to cause a hip fracture: (1) impact near the hip; (2) failure of active protective mechanisms (e.g., using the outstretched arm to arrest the fall); and (3) insufficient passive energy absorption by local soft tissues. Under these three conditions, sufficient force can be transmitted to the proximal femur to exceed its structural capacity and fracture the hip.

Previous studies have examined how risk for hip fracture depends on the mechanics of the fall itself. Relevant biomechanical factors include the height of the fall, impact to the hip, and the direction of the fall [14, 27, 47, 58]. Greenspan and colleagues [47] found that falling to the side increased the risk of hip fracture by a factor of 6, due to the greater chance of hip impact during a sideways fall compared with a fall in any other direction. Hayes and colleagues [27] found that a direct impact to the hip increased the odds of hip fracture by 21.7-fold among nursing home residents. Falling from standing height or higher increased the risk by 1.5-fold, and falling to the side increased the risk by 5-fold. In line with this study, Nevitt and Cummings [14] also found that impacting the hip was associated with a 32.5 increased odds of hip fracture in elderly women living in the community. Schwartz and colleagues [58] found the odds for hip fracture in elderly men was increased 97.8-fold by impacting the hip, and 5.3 by falling sideways. These studies strongly support the notion that the mechanics of the fall is at least as important as bone density in determining the risk for hip fracture.

1.3.3. Risk factors for head injury during falls

In contrast to the considerable amount of research that has been conducted on fall-related hip fractures in older adults, few studies have examined risk factors for head injury during falls in older adults, the most significant of which is traumatic brain injury

(TBI). TBI is physical injury to brain tissue that temporarily or permanently impairs brain function [73]. Diagnosis of TBI is suspected clinically and, in severe cases, confirmed by the detection of lesions or abnormalities through computed tomography (CT) imaging. The most common causes of TBI in older adults are falls (accounting for more than 65% of cases), followed by motor vehicles (15%), and assault/intentional injury (7%) [74, 75]. There are dramatic differences in the emerging prevalence of hip fractures and TBI. While the total number of hip fractures has continued to increase annually with the aging of the population, in Canada (and several other countries) there has been a plateau in recent years in the age-adjusted rate of hip fractures – perhaps related to nutrition, fall prevention efforts, and osteoporosis medication [76, 77]. At the same time, the age-adjusted rate of fall-related TBI in those over age 80 has increased 3-fold over the past 30 years in Finland [78], and more than doubled over the past 10 years in Australia [10]. Similar trends have been reported by others [75, 79-83]. TBI now accounts for 50% of deaths from falls in seniors. The reasons for these trends have not been identified. One contributor may be the growing frequency of falls in the frailest older adults [84]. Another may be the increased use of anticoagulants and antiplatelet agents, which contribute to the greater chance of intracranial bleeding once an impact occurs to the head during a fall [10, 85-87].

While the mechanisms of fall-related brain injury in older adults are not fully understood, a direct impact to the head increases the risk for brain injury due to the high accelerations and relative movement of the brain inside the skull at impact [56]. Clinical studies have reported that falls from standing height or lower cause more than 60% of traumatic brain injuries in older adults [9, 10, 84]. Biomechanical studies showed that falls from bed height can result in more than 40% chance of a serious brain injury if an impact occurs to the head [88, 89].

1.3.4. Protective mechanisms for reducing injury risk during a fall

Young adults seldom suffer hip fracture from a fall, but instead experience a relatively higher frequency of wrist fractures [90, 91]. This trend is reversed in the very old who suffer higher rates of hip fracture than wrist fracture [92]. Age-related declines in bone strength certainly contribute to the increased susceptibility of older adults to hip fracture. However, research has shown that the energies available in a typical fall from standing height exceed those required to fracture both the young and the elderly proximal femur neck [93, 94]. This suggests that changes occur with age in not only the capacity to prevent falls, but also the effectiveness of protective responses to reduce the severity of falls. Perhaps the most common (and important) of these responses is impacting the ground with the outstretched hands to arrest downward movement of the trunk [49]. Epidemiologic studies have reported that impact to one or both hands decreased the risk for hip fracture 3-fold [47, 58]. In a laboratory study, young adults tended to avoid hip impact by rotating their trunk forward during descent to land on both outstretched hands [48]. Other protective mechanisms that may act to reduce the impact velocity on the hip include attempts to recover balance by stepping and grasping [49, 95, 96], and squatting during descent to absorb energy in the lower extremity muscles, as is done during sitting [97]. Moreover, head impact may be avoided by flexing the hip, trunk, and neck during the descent and impact stages of the fall [98].

1.3.5. Physiological influences on protective responses

Previous clinical research showed that risk for hip fracture increases with impaired vision and cognitive impairment, independent of bone density and frequency of falls [60, 99], suggesting that these factors may influence the mechanics of falls [60, 72]. Furthermore, women tend to be at higher risk for injury during falls [79, 100-102], due perhaps to lower muscle strength compared to men [103, 104].

These observations suggest that the effectiveness of protective responses for avoiding injury during a fall may be influenced by physiological changes associated with aging. However, we require improved understanding of the associations among older adults between physiological factors and the spectrum of fall protective responses. Most studies to date have focused on how balance recovery responses (e.g., stepping or reaching responses) are affected by factors such as age, sex, vision, muscle strength, and neurological diseases such as Parkinson’s and Alzheimer’s disease [105-109]. Examination of protective responses related to safe landing (i.e., executed during the descent and impact stage of the fall) have been limited to laboratory studies with young adults [48, 49, 53, 110-112].

While several mechanisms have been proposed to explain the association between cognitive impairment and risk for falls and fall-related injuries, improved evidence is required of how cognitive impairment influences the mechanisms of falls in real life. Impairments in executive function may increase impulsiveness or risk taking, or the ability to allocate cognitive resources between competing demands (related to balance versus secondary activities). The performance of attention demanding tasks impairs postural control in laboratory experiments, especially during daily activities such as walking and turning [106, 107]. Evidence suggests that divided attention may also influence the effectiveness of safe landing responses. Shankar et al [110] used a dual-task paradigm to investigate the role of attention on the ability to employ specific protective responses during a fall. In this experiment, 19 young women participated in both control and secondary attention trials where they were released from a sideways leaning position, causing them to fall to their right onto a gym mat. Participants were instructed to rotate after release to avoid hip impact. In the secondary attention trials, participants were listening to a story via headphones and reciting the spoken text out loud. Results showed that hip impact occurred more often in trials involving the secondary attention task, due to a longer delay in the initiation of body rotation.

Few studies have examined the circumstances of falls and their association with physiological factors in the challenging LTC environment, where residents are twice as likely to fall when compared to community dwelling older adults [19], and suffer higher rates of fall-related injuries [113]. In order to develop intervention strategies targeted to this frailer population, we require a better understanding of the mechanics of falls experienced by older adults in LTC, and the factors that influence risk for injury.

1.4. Accuracy of incident reports in describing fall characteristics in LTC

Fall incident reports are commonly used to document falls in LTC and acute care settings, and guide the development and evaluation of fall prevention and treatment strategies [14, 39, 114, 115]. Incident reports are mandated by law in British Columbia and a condition for accreditation of LTC facilities [116]. They are completed by care staff who may interview the faller or witnesses within 24 hours of the event [39, 114, 117]. These reports must describe the time and location of the fall, and associated injuries. They must also describe steps towards fall prevention. With regard to the latter, the reports often probe the cause and activity at time of fall, use of mobility aids, associated environmental hazards, and whether the fall was witnessed [29, 35, 44, 114]. However, the accuracy of fall incidence reports is poorly understood. Even in LTC, most falls are unwitnessed [114, 118], and about 25% of falls are not adequately documented [114, 115]. When present, the reliability of information has been questioned [119, 120], given the challenges for older adults, especially those with cognitive impairment, in accurately recalling and describing the circumstances of falls [121, 122]. Cummings and Nevitt [119] found that older adults in the community were unable to recall 13% of falls occurring in the past 3 months, and 32% of falls occurring over the past 12 months. Others have found, not surprisingly, that individuals with cognitive impairment were more likely to forget falls [122, 123].

We were aware of only one study specifically examining ability to accurately recall the characteristics of falls. Feldman and Robinovitch [120] conducted a laboratory experiment with 41 young participants who experienced a fall after a sudden sideways translation applied to the platform that they stood on. Immediately following the fall, participants were queried on the details of their fall, including the fall direction and impact body parts. Data were compared to those recorded by an 8-camera motion capture system. Most participants were unable to accurately report which body parts impacted, or whether they took a step to recover balance, even when they described their recall as “confident”. This study suggests that even young adults have difficulty in accurately describing the circumstances of falls immediately after the event occurred.

1.5. Video capture of real-life falls in LTC

Falls captured on video provide a “moving picture” of the event [124], and objective evidence to inform prevention strategies. In 1990, Holliday and colleagues reported the first observations on the circumstances of real-life falls in older adults captured on videotape [125]. In this study, 25 falls by 17 individuals in a geriatric care facility were captured on videotape during a 15-month period. Videos were reviewed by multidisciplinary experts to determine the characteristics of falls. The authors found that 36% of falls were what they regarded as primarily related to environmental factors (e.g., floor transitions, lighting conditions, footwear), while 60% were related primarily to “intrinsic” factors (e.g., gait impairment). In terms of the activity at time of falling, 68% of falls occurred during walking, 12% during standing, and 16% during transferring (rising or sitting). Balance recovery attempts by stepping were observed in 40% of cases. Most falls involved impact to multiple body sites. Among them, pelvis impact occurred in 40% of cases, knee impact in 25%, and hand impact in 13% of cases. This study provided the first observational evidence based on video collection and analysis of the characteristics of real-life falls in older adults.

More recently, Vlaeyen and colleagues [126] described the circumstances of falls captured on video in private areas (e.g., bedrooms and bathrooms) in assisted living and residential care facilities. This study included 26 falls experienced by three older adults. Video data were analyzed by two researchers to determine the circumstances of falls. Results showed that 35% of falls occurred during transferring to or from bed, sofa or wheelchair, 27% occurred during walking, 19% during bending down, and 15% during dressing. In 54% of falls, participants used a walker or a wheelchair. The majority of falls resulted in initially falling backwards (54%) and landing backwards (62%). Head impact occurred in 62% of cases, pelvis impact in 89%, and elbow or forearm in 62%. This study demonstrated the feasibility of obtaining objective evidence of falls in the private rooms. However, similar to Holliday et al [125], the small sample of participants and falls may limit the generalizability of the study results to the larger population.

1.6. Summary of the goals

My PhD thesis builds on previous studies by utilizing a large library of real-life falls by older adults, captured on video in two LTC facilities, to examine the associations between fall characteristics, physiological factors, and injury risk. The conceptual model driving my efforts is shown in Fig 1-1.

In Chapter 2, I describe the development of a structured questionnaire (based on existing conceptual models in the literature) used by a team of experts to analyze video footage of real-life falls to derive quantitative or categorical outcomes related to the initiation, descent and impact stages of the fall. I also describe the results of tests of the inter-rater and intra-rater reliability of the questionnaire.

In Chapter 3, I describe results from comparing characteristics of the fall described on incident reports (completed by nursing staff) to those obtained from video analysis of the fall. I focused on the following research questions: (1) What was the agreement between video analysis and incident reports for the circumstances of falls (cause of imbalance, activity of the time of falling, and use of mobility aids at time of fall)? (2) Was the agreement between incident reports and video analysis greater for witnessed falls than unwitnessed falls? By identifying areas of agreement and discrepancy, my results should contribute to the development of more accurate fall incident reporting in the LTC environment.

In Chapter 4, I analyzed our video database to examine the prevalence of and biomechanical risk factors for head impact during falls in LTC. I focused on the cause of imbalance, activity at time of fall, initial fall direction, landing configuration, and the occurrence of hand impact. I also examined how risk of head impact is influenced by physiological factors (e.g., age, sex, ADL performance, cognitive performance, vision, disease diagnoses, use of medications) acquired from Minimum Data Set. I focused on the following research questions: (1) What is the prevalence of head impact in LTC? (2) What are the biomechanical and physiological risk factors for head impact?

In Chapter 5, I used the same dataset (as Chapter 4) to examine the prevalence of hip impact and how biomechanical factors (e.g., cause of imbalance, activity at time of fall, fall direction, hand impact, stepping responses, and use of mobility aids) and physiological factors (e.g., ADL and cognitive performance, vision, disease diagnoses, and use of medications) influence the risk of hip impact during falls. I focused on the following research questions: (1) What is the prevalence of hip impact from falls in LTC? (2) What are the biomechanical and physiological risk factors for hip impact? I assumed that there would be no link between risk for head impact and hip impact in the event of a fall (as discussed in Section 1.3). Accordingly, I separately examined the risk factors for head impact (in Chapter 5) and hip impact (in Chapter 4).

This thesis project was funded by CIHR Team Grants, which supported a program of research titled “Technologies of Injury Prevention for Seniors (TIPS)”. My role in this project included identifying the research questions, experimental design, and data analysis, under the supervision of my thesis committee. I also took a lead role in working with stakeholders to develop data collection protocols and questionnaires, collecting and analyzing video data, fall incident reports, and Minimum Data Set health records, and interpreting and disseminating my study results through presentations at local, national and international meetings and conferences, publication of peer-reviewed journal articles, and through this thesis document.

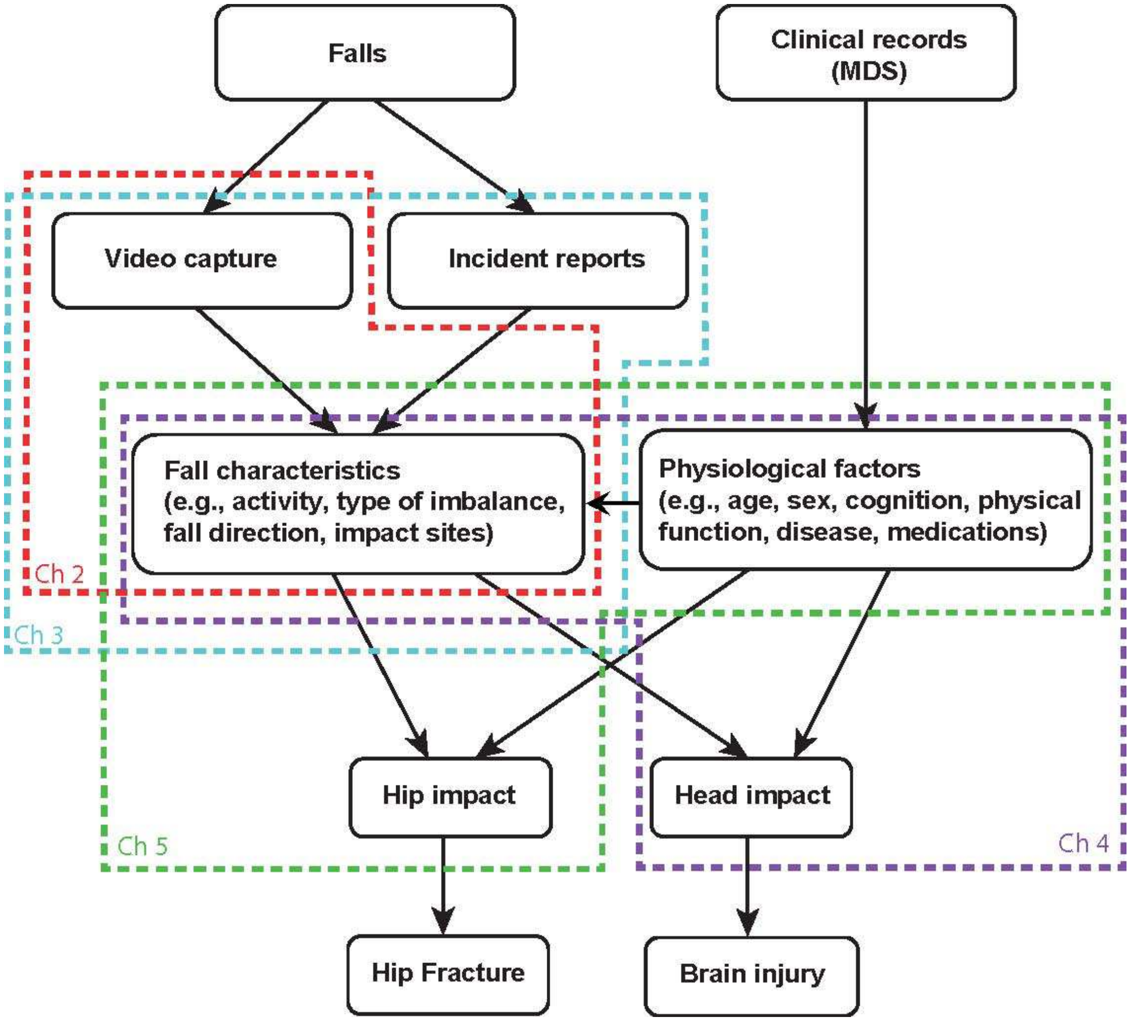

Figure 1-1: The conceptual model of this thesis research – "video capture of falls and the risk factors associated with head impact and hip impact during falls".

Chapter 2. Development and reliability testing of a fall video analysis questionnaire for analyzing real-life falls captured on video in long-term care

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Abstract

Background: Falls are the number one cause of injuries in older adults, and are particularly common in long-term care (LTC). Lack of objective evidence on the mechanisms of falls in this setting is a major barrier to prevention. Video capture of real-life falls can help to address this barrier, if valid tools are available for data analysis. To address this need, we developed a 24-item fall video analysis questionnaire (FVAQ) to probe key biomechanical, behavioural, situational, and environmental aspects of the initiation, descent, and impact stages of falls. We then tested the reliability of this tool using video footage of falls collected in LTC.

Methods: Over three years, we video-captured 221 falls experienced by 130 individuals in common areas (e.g., dining rooms, hallways, and lounges) of two LTC facilities. The FVAQ was developed through literature review and an iterative process to ensure our responses captured the most common behaviours observed in preliminary review of fall videos. Inter-rater reliability was assessed by comparing responses from two teams, each having three members, who reviewed 15 randomly-selected videos. Intra-rater reliability was measured by comparing responses from one team at baseline and 12 months later.

Results: In 17 of the 24 questions, the percentage of inter- and intra-rater agreement was over 80% and the Cohen's Kappa was greater than 0.60, reflecting good reliability. These included questions on the cause of imbalance, activity at the time of the fall, fall direction, stepping responses, and impact to specific body sites. Poorer agreement was observed for footwear, contribution of clutter, reach-to-grasp responses, and perceived site of injury risk.

Conclusions: Our results provide strong evidence of the reliability of the FVAQ for classifying biomechanical, behavioural, situational, and environmental aspects of falls captured on video in common areas in LTC. Application of this tool should reveal new and important strategies for the prevention and treatment of falls and fall-related injuries in this setting.

Keywords:

Falls, fall mechanisms, older adults, injuries, long-term care, questionnaire, video analysis, reliability

2.1. Background

Falls are the cause of over 90% of hip and wrist fractures [13] and 65% of head injuries in older adults [127]. Developing improved strategies to prevent these events is an essential health priority. This is especially true for the long-term care (LTC) environment, where the complex medical status of residents causes rates of falls to be 2-3 fold higher than among community dwelling seniors [18, 19], and creates unique challenges to prevention [128].

An important barrier to fall prevention is lack of objective evidence on the mechanisms of these events - how and why they occur. Our current understanding of the circumstances of falls is based on interviews or incident reports, exploring a limited set of outcomes in community-dwelling individuals [14, 35, 42, 129]. However, most falls are unwitnessed, and accurately recalling the circumstances of falls is challenging even for young adults [120, 130, 131]. Furthermore, fallers may tend to rationalize falls as being due to an external, unavoidable cause to avoid the perception of vulnerability [119, 120, 130, 131].

Video technology provides a means for capturing footage of real-life falls in high-risk environments such as LTC [124, 125, 132], and providing information on the biomechanical and situational aspects of falls in these settings. This information can complement clinical data (on disease diagnoses, medications, and functional status) in revealing the mechanisms of falls, and in designing and selecting prevention efforts at a population or individual level. However, this approach necessitates the development of reliable methods for extracting relevant outcomes. The present study addresses this need by developing and evaluating the inter-rater and intra-rater reliability of a 24-item questionnaire for analyzing fall mechanisms from video footage of falls captured in common areas of LTC facilities.

2.2. Methods

2.2.1. Video capture of falls.

Between March 2007 and June 2010, we collected video footage of 221 falls experienced by 130 different residents from networks of digital video cameras installed in common areas (dining rooms, lounges, and hallways) in two LTC facilities in the Greater Vancouver area: Delta View Life Enrichment Centre, a 312-bed multi-level facility located in Delta, BC, and New Vista Society Care Home, a 236-bed facility located in Burnaby, BC. In both facilities, no stairs were located in the areas accessible to residents. The Delta View facility had a network of 216 digital cameras, while New Vista facility had 48 cameras. All cameras were networked to digital video recorders, which stored video data at a resolution of 640 x 480 pixels and a frame rate of 15 frames per second.

At both facilities, the occurrence of a fall (defined as “an unexpected event in which the resident comes to rest on the ground, floor, or lower lever” [26]) triggered care personnel to complete a structured incident report, as required by the Health Act of the Province of British Columbia. Members of our research team communicated daily with care personnel to review incident reports, identify falls occurring in common areas, and retrieve corresponding video footage. In 2010 at Delta View, 45% of falls occurred in common areas, of which 65% were captured on video. In 2010 at New Vista, 34% of falls occurred in common areas, of which we captured 28% on video. This study was approved by the Office of Research Ethics at Simon Fraser University and Fraser Health Authority. At the time of admission, each resident or proxy provided written permission to the facility to acquire video footage in common areas, for the purpose of resident safety. These data were shared as secondary data with our research team. We also obtained written consent from some participants to use their photographs and/or video images for the purpose of presentations or publications.

2.2.2. Resident characteristics.

Residents of New Vista had an average age of 81 years (SD = 13), and 67% were women. Residents at Delta View had an average age of 82 years (SD = 10), and 61% were women. Among the 15 participants included in this study, the mean age was 82 years (SD = 12), and 47% (n = 7) were women. As described previously [132], among residents captured falling who provided us with consent to access their health records, 34% had Alzheimer's disease, 13% had diabetes, 31% had hypertension, 19% had stroke, and 6% had Parkinson's disease. These prevalence data were similar to those observed among fallers not captured on video, and to the overall profile of residents at the two LTC facilities.

2.2.3. Video analysis questionnaire.

Our fall video analysis questionnaire (FVAQ) included 24 primary questions probing biomechanical, situational, behavioural, and environmental aspects of falls observed in the video footage (Figure 2-1; Appendix: Fall Video Analysis Questionnaire

(FVAQ) – short form version). While falls result from interactions between physiological (intrinsic), environmental, and situational factors, video analysis itself cannot reveal physiological causes of falls (or the intentions of the faller). Instead, the FVAQ provides meaningful categorization of biomechanical features that may be important to consider, along with clinical data, in improving our understanding of the cause and prevention of falls. For each question, definitions and examples for each category (level of responses) were provided in a comprehensive instruction manual (Appendix 2: Fall video analysis instruction manual (short version)). We designed the FVAQ to be completed by a team of evaluators, to reduce the biases inherent in individual evaluators and allow interdisciplinary perspectives [133]. While there is no standardized approach currently for describing the mechanisms of falls, the FVAQ was based on two established conceptual models. The first model was proposed by Hayes et al. [134] and Noury et al. [28], and discusses falls as having four sequential stages: initiation, descent, impact, and post fall. The second model was proposed by Cummings et al. [72], and hypothesizes that injury risk during falls is governed by fall direction and energy-absorbing mechanisms (protective responses such as upper limp fall arrest). In selecting the responses for each question in the FVAQ, we also considered previous studies on self-reported fall circumstances (Table 2-1), and observations on fall characteristics emerging from our preliminary viewing and discussion of the fall videos. We also considered the approach used by Holliday and co-workers in analyzing video recordings of real-life falls captured in a Toronto area LTC facility [125]. In that study, a team reviewed each fall video to identify the activities associated with falls, environmental and behavioural contributors, balance recovery responses, impact sites, and assistive devices. Below, we summarize the FVAQ questions related to fall initiation, descent, and impact. We did not consider post-fall behaviour, such as the ability to rise after falling [28], since preliminary viewing of videos indicated that, for the vast majority of falls in common areas in LTC, residents are assisted by care staff to rise after falling. As such, a study of post-fall behaviour in this setting enters the domain of patient-care provider interactions, beyond the scope of our current study. Nor did we consider the consequences of falls.

For fall initiation, we considered the biomechanical cause of imbalance, the activity at the time of the fall, and situational and environmental factors that have been associated with falls. These include clutter or tripping hazards, poor lighting, floor transitions, poor footwear, use of assistive devices, and held objects. Collectively, these items provide insight on “why” and “how” the fall occurred. We classified the biomechanical cause of imbalance based on the most common self-reported causes of falls in community-dwelling older adults (“trip/ stumble,” “slip,” “incorrect transfer/shift of body weight,” “collapse/loss of consciousness,” and “loss of support with external object”) [2, 29, 35, 36, 43, 44]. The FVAQ included these five categories, along with “hit/ bump” (Table 2-3). We defined incorrect transfer/shift of body weight as loss of balance due to self-induced displacement of the body’s centre-of-gravity beyond the base of support (an “internal” rather than “external” perturbation). We classified activity at the time of falling into general categories, without consideration of the intent of the action (e.g., “walking”, as opposed to “walking to the dining room”). The most common reported activities leading to falls are walking, and transferring to or from a seated or lying position [14, 29, 43, 44, 135]. The FVAQ included these along with “standing” (Table 2-3).

For fall descent, we considered the initial direction of the fall and attempts to recover balance or prepare for landing (Figure 2-1 & Table 2-3). Fall direction is an important determinant of injury risk, with sideways falls causing increased risk for hip fracture [69], and forward falls causing increased risk for wrist fracture [14]. As discussed below, we considered initial fall direction separately from body configuration at landing, to account for body rotation during descent. We also investigated the appearance of balance recovery responses including stepping and grasping [50, 95], which are important markers of neurological function, which, even when unsuccessful in preventing a fall, may absorb energy and reduce injury risk [49]. Finally, we examined whether active attempts were made to move the hand(s) or arm(s) into a position to arrest the fall.

For fall impact, we considered the landing configuration (forward, backward, or sideways) and the occurrence of contact to key body sites (head, pelvis, torso, hand/wrist, elbow/forearm, knee, and shoulder) (Table 2-3). Collectively, these items provide insight on attempts to configure the body into safe landing configuration and understanding on how the energy of the fall was absorbed or “managed.” Individual may actively modify the direction of a fall during descent[48]. Accordingly, in addition to examine the initial direction of the fall (as discussed above), we separately examined landing configuration. Impact to the head governs risk for brain injury [56], while impact to the hip or wrist dramatically increases risk for fracture at these respective sites [14, 69]. However, upper extremity impact is also often protective in arresting the downward momentum of the trunk and avoiding impact and injury to the head [49]. The forces (and tissue stresses) generated during landing also depend on the number and timing of impacts to the various body parts, and on impact velocity, mass, and stiffness [136]. While recognizing it is challenging to probe these issues through a video questionnaire, we included questions on the perceived site of greatest energy absorption and the perceived site of greatest injury risk.

2.2.4. Reliability testing of video analysis.

Reliability testing was conducted over the course of one year. 15 fall videos were selected randomly (using a random number generator to minimize bias) from our database. Seven (47%) videos were recorded at New Vista and 8 (53%) were from Delta View. Four (27%) of the falls occurred relatively close to the camera, 5 (33%) occurred at a far distance, and 6 (40%) occurred at a moderate distance. The time interval between fall initiation (loss of balance) to fall impact ranged from about 700 ms (for a rapid trip) to 3000 ms (for a fall related to incorrect weight shifting); and the corresponding number of video frames ranged from 10 – 45. There were no major body occlusions of body segments or missing frames.

Our sample size of 15 falls was based on published guidelines for observer agreement studies [137]. We estimated a priori that (for a given question) the average percentage of agreement between the two teams would be 85 percent (or 15 percent disagreement). In order to detect a desired 90% confidence interval of between 0 and 30 percent disagreement, we calculated a minimal required sample of 15 observations.

We first evaluated inter-rater reliability by having two teams separately analyze the selected 15 videos. Each team consisted of three members, who were research assistants or graduate students trained by co-author SNR using the previously mentioned instruction manual. Team members were blinded to answers from the other team. Furthermore, team members were prevented from examining corresponding fall incident reports completed by LTC care providers (while teams would normally have this information, this created a worse-case scenario for reliability testing). Intra-rater reliability was evaluated by having one team (consisting of the same three members) re-analyze the same 15 videos one year later, while blinded to their previous answers. Each team was led by a chair, who provided instructions and recorded the team's answers to each question. The videos were played using Windows Movie Maker (version 5.1, 2007 Microsoft Corporation). During analysis, the team members first viewed the video at normal speed, and then through frame-by-frame review while discussing and reaching consensus on the most appropriate answer to each question. We did not include "can't tell" responses. Rather, for each question, the team was instructed to select the best available answer, along with the estimated probability (between 1-100%) of the answer being correct. On average, each fall was examined for approximately 20 minutes.

2.2.5. Statistical analysis.

For each question, we report the percentage of agreement between the two teams, calculated as the number of cases with the same response divided by the total number of cases, and the corresponding Cohen's Kappa coefficient [138]. Landis and Koch [139] recommended that a Kappa value of >0.8 reflects "outstanding agreement," 0.6-0.79 reflects "good agreement," and 0.4-0.59 reflects "moderate agreement." Accordingly, we considered questions with a percentage of agreement higher than 80% and a Kappa value greater than 0.6 as exhibiting "good reliability." We also examined the association between agreement in responses and probability reported by the teams in the answer being correct using Pearson's Correlation.

2.3. Results

2.3.1. Inter-rater reliability.

19 of the 24 questions had good inter-rater reliability, with a percentage of agreement over 80% and Cohen's Kappa greater than 0.60 (Table 2-3). Among all questions, the average percentage of agreement was 87% and the average Kappa was 0.69. The mean probability reported by teams in selecting the correct answer ranged from 84% - 100% for one team, and from 90% - 100% for the other team. There was significant correlation between agreement in responses and probability in the answer being correct ($R^2 = 0.37$; $p = 0.001$).

2.3.2. Intra-rater reliability.

18 of 24 questions had good intra-rater reliability (Table 2-3). The average percentage of agreement over all questions was 89% and the average Kappa was 0.74. A total of 17 of 24 questions demonstrated both good inter-rater and good intra-rater reliability. The mean probability reported by teams in selecting the correct answers ranged from 90% - 100% for the baseline analysis, and from 85% - 100% for the repeat analysis. Again, there was significant correlation between agreement in responses and probability in the answer being correct ($R^2 = 0.31$; $p = 0.005$).

2.3.3. Fall initiation.

Good inter- and intra-rater reliability was observed for biomechanical cause of imbalance, activity at the time of the fall, use of mobility aids, height of the fall, and floor conditions (Table 2-3). However, there was poor agreement for footwear and the contribution of clutter. For held objects, the inter-rater agreement was moderate, while the intra-rater agreement was high. Incorrect weight shifting, loss of support with an external object, and tripping were the most commonly selected causes of imbalance, collectively accounting for 93% of responses (Table 2-2). Walking, standing, and transferring to sitting or lying were the most commonly selected activities at the time of falling, accounting for 89% of responses.

2.3.4. Fall descent

Good inter- and intra-rater reliability was observed for initial fall direction and stepping responses (Table 2-3). There was high agreement but only moderate Kappa values for reach-to-grasp responses. The most commonly selected fall directions were backward and sideways, accounting for 42% and 31% of responses, respectively. Observable attempts to recover balance by stepping were noted in 42% of responses (Table 2-2).

2.3.5. Fall impact

Good inter- and intra-rater reliability was observed for landing configuration and impact to the head, pelvis, hand, and knee (Table 2-3). Only moderate agreement was observed for torso impact, and perceived sites of greatest injury risk/ impact severity. The most commonly selected landing configuration was backward (Table 2-2), accounting for 71% of responses. There were positive responses for impact to the head in 42% of cases, for impact to the hand(s) in 71% of cases, and for impact to the pelvis in 100% of cases. Most falls were reported to involve impacts to multiple body sites (head, torso, pelvis, knee, hand, elbow, and shoulder). In inter-rater testing, the mean number of impact sites was 4.0 (SD = 1.9) for one team, and 4.2 (SD = 1.8) for the other, with positive correlation between teams in the number of impacting sites ($R^2 = 0.84$; $p<0.001$).

2.4. Discussion

Falls are the number one cause of injury in older adults, and are particularly common in LTC. Lack of objective evidence on the mechanisms of falls in this setting is a major barrier to prevention. Video capture of real-life falls can address this barrier, if valid analysis tools are available. In this study, we developed and evaluated the reliability of a comprehensive questionnaire for analyzing falls captured on video in LTC. We focused the FVAQ on the initiation, descent, and impact stages of falls [28, 134] and the mechanisms that influence injury risk [72], using an iterative process to ensure our responses captured the most common behaviours observed in preliminary review of fall videos.

Our results provide strong evidence of the reliability of the FVAQ. We found that 17 of the 24 questions met our criteria for good inter-rater and intra-rater reliability. Teams rated their probability in selecting the correct answer between 84 - 100% (depending on the question), reflecting their strong confidence, and the adequacy of our video collection techniques, in identifying key features of the fall (barring significant occlusion of body parts from the camera view, which did not occur). A significant correlation existed between agreement and probability, although probability explained only 37% and 31% of the variance in inter-rater and intra-rater agreement, respectively.

In completing the FVAQ, the team often faced challenges related to camera resolution, distance between the faller and the camera. In each case, only a single camera recorded the fall. Clearly, improvements in the number and resolution of cameras should improve the reliability of most questions in the FVAQ. However, of the six poorly scoring questions, only one - type of footwear – was clearly related to video quality (e.g., distance between the faller and the camera). More complex challenges arose for other items, which might be addressed through refinements to the questions and/or instruction manual for improved clarity. For example, we observed poor reliability for contribution of clutter in causing the fall. This may more relate to the ambiguity in our definition of clutter, or the challenge of attributing casual links between falls and environmental features [36], aside from cases of obvious trips over obstacles (which made up only 13% of our sample). We observed moderate reliability for site of greatest perceived injury risk/ impact severity. This may relate to difficulties in judging the injury potential of impacts to multiple body sites (on average, impact was reported to occur to 4 body sites). Reach-to-grasp responses showed good agreement but only a moderate

Kappa value, perhaps due to its low frequency of occurrence creating a high probability for chance agreement [140].

The 24 questions on the FVAQ probe previously hidden aspects of falls and contribute new information to guide fall prevention efforts. For example, information on the biomechanical causes of imbalance and activities leading to falls (both of which exhibited strong reliability) helps to guide improved fall risk assessment and balance training protocols, along with efforts to reduce environmental hazards and create safer movement environments supports [132]. Information on fall severity (impacting body parts) can provide insight on injury mechanisms and help guide the design of protective padding (e.g., hip protectors [141]) and compliant “safety” flooring [142]. Attempts to prevent or lessen the injury potential of the fall (through balance recover by stepping, or arresting the fall with the upper limbs) are important neurological markers, that may also help in guiding exercise-based fall injury prevention programs.

However, there are important limitations to our study. We focused on assessing the internal reliability (reproducibility of results) of the FVAQ. Additional studies are required to examine external validity, for example by relating FVAQ responses to data from fall incident reports, observed injuries, risk for future falls, and the nature of future falls. Furthermore, we designed the FVAQ to focus on the situational and environmental context of falls in common areas of two LTC facilities (e.g., hallways, dining rooms, and living rooms). Accordingly, it may not capture the range of mechanisms of falls in bedrooms, bathrooms, and stairways, or among healthier older adults living in the community. Furthermore, the FVAQ probes a limited set of features of the built environment, behavioural factors (such as secondary attention tasks or aggression), and disease-related behaviours (such as freezing in Parkinson’s patients, or asymmetries in limb movements in stroke patients). Finally, we recognize that currently, there is limited partnering between researchers and care providers in LTC for video capture of falls. We hope that our model for data collection and analysis facilitates growth in the applications of this tool to LTC and other high risk settings, such as hospitals or senior centres [125, 143]. Further “analysis packages” may build on the core template provided by the FVAQ, to probe issues such as pre-fall or post-fall behaviour, additional aspects of balance recovery or fall protective responses, or questions of known or suspected relevance to specific clinical subgroups or environments. Additional iterations should be based on a consensus process between researchers and stakeholders to agree on the right questions and response categories, and establish acceptable approaches for data collection and linking to health information.

In summary, this study presents and establishes the reliability of a questionnaire for analyzing the mechanisms of falls captured on video in common areas of LTC. The FVAQ opens a window on key aspects of fall initiation, descent, and impact. When combined with health data, the FVAQ should provide researchers and clinicians with an improved understanding of the mechanisms and guidance in the prevention of falls and fall-related injuries in the high-risk LTC setting.

A

Initiation stage (1, 2)	Descent stage (3, 4)	Impact stage (5, 6)
Cause of imbalance	Initial fall direction	Landing configuration
Activity at time of fall		Floor material
Mobility aids	Stepping responses	Site of greatest energy absorption
Held objects		Site of injury risk/ impact severity
Height of fall	Reach-to-grasp responses	Head impact
Footwear		Pelvis impact
Floor conditions - Wet/Dry		Torso impact
Floor conditions - Transition		Hand/ wrist impact
Lighting		Elbow/ forearm impact
Contribution of clutter		Knee impact
		Shoulder impact

B

Figure 2-1: Sample video snapshots and the classifications of fall characteristics.

(A) Sequence of images from a video recording of a real-life fall of an older woman. (B) Characteristics of the initiation, descent and impact stages of falls probed by the 24-item fall video analysis questionnaire (FVAQ). Note the individual shown has provided the team with written consent to include her image in publications related to this study.

Table 2-1: Summary of the causes and activities associated with falls in older adults.

Author (Setting)	Category		
	Cause (% of falls)	**Activity (% of falls)**	**Other (% of falls)**
Overstall et al., [35] (Hospital and community)	Tripping (47) Drop attack (12) Giddiness (9) Loss of balance (8)	After rising (6) Turning head (5)	Miscellaneous (12)
Brocklehurst et al., [135] (Hospital and community)	Trip (20) Lost balance (32) Drop attack (23) Loss of consciousness or "other" (20)	Walking Standing Postural change	
Lach et al., [36] (Community)	Extrinsic falls (55) slip (27) trip (21) displaced center of gravity (7) Intrinsic falls (31) mobility system failure (4) impaired balance (9) sensory impairment (1) cognitive impairment (12) impaired consciousness (6) Non-bipedal stance (5) self-generated (5) support failure (<1) Non-classifiable falls (9)		Contributing factors (% of fallers) sensory (28) shoes (26) hurrying (14) external load (12) not common activity (11) assistive devices (5) medication/alcohol (2)
Cumming & Klineberg, [44] (Hospital and community)	Trip (40) Slip (10) Leg gave way (10) Postural change (12) Dizziness loss of consciousness (10) Other (18)	Walking (42) Being over (5) Getting up (14) Sitting down (4) Turing around (8) Using stairs (3)	Location of the fall own residence (74) outside (16) inside shop or club (6)

Author (Setting)		Category	
	Cause (% of falls)	Activity (% of falls)	Other (% of falls)
Topper et al., [42] (Assisted living)	Base-of-support (BOS) perturbation (46) transfer with BOS problem (8) trip or tangle (23) slip (10) Center-of-mass (COM) perturbation (28) pushed (5) collision (0) reaching, bending, turning (18) transfer without BOS problem (4) No obvious perturbation (NOP) (14) loss of consciousness (3) no loss of consciousness (8)		Don't know (15)
Berg et al., [43] (Community)	Trip (34) Slip (25) Misplaced step (12) Loss of balance (9) Legs giving way (4) Knocked over (4) Loss of support (3) Other (9)	Walking on level ground (24) Walking on uneven ground (24) Hurrying to get work done (12) Stair ascent and decent (14) Working in the yard (9) Carrying something heavy (9) Looking of turning (7) Exercising (7); Other (7)	Location of the fall home (58) away from home (42) Time of the fall morning (30) afternoon (52) evening (14) night (4)
Wild et al., [29] (Hospital and community)	Fell suddenly without warning (48) Trip, slip, miss (21) Body gave way (11) Dizziness and giddiness (9) Light-headed (6) Black-out (5)	Walking (53) Change of position (23) Stair ascend or descend (13) Standing or dressing (10) Fell out of chair (5) Other (3)	Environmental hazards poor lighting (22) stairs (13) carpets or rugs (4) wet floor (4)

Table 2-2: Number of response reported by the team in selecting answers for the key questions for the inter-rater and intra-rater testing (n = 15 videos)

Question	Inter-rater	Intra-rater	
	Team 1 pre	Team 2 pre	Team 2 post
	Number of response being selected		
Cause of imbalance			
i. Slip	0	0	0
ii. Trip/stumble	1	2	3
iii. Hit/bump	1	1	1
iv. Leg collapsed/loss of consciousness	0	0	0
v. Incorrect transfer/shift of body weight	7	5	5
vi. Loss of support with external object	6	7	6
Activity at time of fall			
i. Transferring to sitting or lying	4	4	5
ii. Transferring from sitting or lying	2	2	1
iii. Seated/wheeling in wheelchair	0	0	0
iv. Walking	4	5	5
v. Standing	5	4	4
Initial fall direction			
i. Forward	1	1	1
ii. Backward	7	7	5
iii. Sideways	6	4	4
iv. Straight down	1	3	5
Stepping response			
i. Yes	6	7	6
ii. No	9	8	9
Landing configuration			
i. Forward	1	1	1
ii. Backward	10	11	11
iii. Sideways	4	3	3
Head impact			
i. Yes	6	7	6
ii. No	9	8	9

Question	Inter-rater	Intra-rater	
	Team 1 pre	Team 2 pre	Team 2 post
Hand impact			
i. Yes	11	10	12
ii. No	4	5	3
Pelvis			
i. Yes	15	15	15
ii. No	0	0	0
Site of greatest injury risk			
i. Head	3	3	2
ii. Pelvis/torso/buttocks	9	9	11
iii. Upper limb	3	3	2
iv. Lower limb	0	0	0

Table 2-3: Percentage of inter-rater and intra-rater agreement, Cohen's Kappa, and mean probability confidence in selecting the answer for each question in the fall video analysis questionnaire (n = 15 videos)

Stage of fall	Question	Inter-Rater Reliability			Intra-Rater Reliability		
		% Agreement	Cohen's Kappa (95% CI)	Mean probability (0-100%)	% Agreement	Cohen's Kappa (95% CI)	Mean Probability (0-100%)
Initiation	Cause of imbalance	87%	0.79 (0.53-1.00)	91	93%	0.90 (0.72-1.00)	94
	Activity at time of fall	93%	0.91 (0.74-1.00)	97	93%	0.91 (0.73-1.00)	97
	Mobility aids	93%	0.89 (0.69-1.00)	95	100%	1.00 (1.00-1.00)	97
	Held objects	73%	0.33 (0.17-0.83)	97	100%	1.00 (1.00-1.00)	98
	Height of fall	100%	1.00 (1.00-1.00)	99	87%	0.71 (0.34-1.00)	99
	Footwear	67%	0.21 (0.19-0.63)	90	67%	0.29 (0.02-0.76)	90
	Floor conditions - Wet/Dry	100%	1.00 (1.00-1.00)	97	100%	1.00 (1.00-1.00)	98
	Floor transition	100%	1.00 (1.00-1.00)	100	100%	1.00 (1.00-1.00)	100
	Lighting	93%	0.84 (0.55-1.00)	97	100%	1.00 (1.00-1.00)	99
	Contribution of clutter	47%	0.14 (0.07-0.35)	94	60%	0.24 (0.07-0.54)	96
Descent	Initial fall direction	80%	0.70 (0.40-0.99)	97	87%	0.81 (0.57-1.00)	96
	Stepping responses	93%	0.87 (0.61-1.00)	97	93%	0.87 (0.61-1.00)	96
	Reach-to-grasp responses	80%	0.44 (0.08-0.97)	94	87%	0.44 (0.15-1.00)	96
Impact	Landing configuration	93%	0.85 (0.57-1.00)	98	100%	1.00 (1.00-1.00)	97
	Floor material	100%	1.00 (1.00-1.00)	100	100%	1.00 (1.00-1.00)	100
	Perceived site of greatest energy absorption	93%	0.84 (0.55-1.00)	95	80%	0.47 (0.02-0.93)	97
	Perceived site of greatest injury risk/ impact severity	67%	0.41 (0.003-0.81)	92	73%	0.47 (0.05-0.90)	94
	Head impact	80%	0.60 (0.19-1.00)	94	93%	0.87 (0.61-1.00)	95
	Pelvis impact	100%	1.00 (1.00-1.00)	99	100%	1.00 (1.00-1.00)	99
	Torso impact	80%	0.60 (0.19-1.00)	95	73%	0.41 (0.051-0.87)	98
	Hand/ wrist impact	93%	0.84 (0.55-1.00)	94	87%	0.67 (0.26-1.00)	97
	Elbow/ forearm impact	93%	0.84 (0.55-1.00)	96	93%	0.82 (0.47-1.00)	98
	Knee impact	93%	0.86 (0.59-1.00)	95	93%	0.86 (0.59-1.00)	96
	Shoulder impact	87%	0.70 (0.32-1.00)	96	93%	0.86 (0.59-1.00)	96

Chapter 3. Agreement between video footage and fall incident reports on the circumstances of falls in long-term care

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Abstract

Objective: Incident reports guide fall prevention efforts in long-term care (LTC) facilities, often based on descriptions of how falls occurred. The validity of these reports is poorly understood. We examined agreement on fall characteristics between fall incident reports and analysis of video footage of real-life falls in LTC.

Design/Setting/Participants: Video capture of 863 falls (by 309 individuals) over six years in common areas of two LTC facilities in British Columbia.

Measurements: We reviewed each fall video with a previously validated questionnaire to determine the cause of imbalance leading to the fall, activity at the time of falling, and use of mobility aids. These data were compared to corresponding information recorded by staff on fall incident reports.

Results: There was agreement between video analysis and incident reports on the cause of imbalance in 45.5% of falls (Kappa = 0.25), on activity at time of falling in 45.1% of falls (Kappa = 0.22), and on use of mobility aids in 79.5% of falls (Kappa =

0.59). When compared to video analysis, incident reports over-reported falls due to slips, and falling while rising and while using a wheelchair or walker. Incident reports also under reported falls due to hit/bump and loss-of-support, and falling while standing and sitting down.

Conclusion: In over 50% of falls, we found discrepancies between fall incident reports and analysis of video footage on the cause of imbalance and activity while falling. Emerging technologies incorporating video capture or wearable sensors should improve our ability to understand the mechanisms and improve the prevention of falls in LTC.

Key words:

Long-term care (LTC), fall incident reports, video analysis, circumstances of falls

3.1. Introduction

Falls are the most frequently reported adverse incident in long-term care (LTC) facilities [144]. Nearly 50% of older adults residing in LTC will fall each year [30]. The complex medical status of residents causes rates of falls and fall-related injuries in LTC to be 2–3 fold higher than among community-dwelling older adults [18, 100]. The annual cost for treating hip fractures in Canada is $1.1 billion, with a disproportionately high portion in LTC [5]. Clearly, developing improved strategies to decrease the frequency and consequences of falls in LTC is an essential health priority.

A major barrier to fall prevention is insufficient knowledge on the causes and circumstances of falls. Our current understanding of falls in the residential and acute care settings relies on incident reports [14, 39, 114, 115], which are completed by care staff who may interview the faller or witnesses [39, 114, 117]. Fall incident reports are mandated by law in British Columbia and a condition for accreditation of LTC facilities [116]. The reports must describe the time and location of the fall, and associated injuries. They must also describe steps towards fall prevention. With regard to the latter, the reports often probe the cause and activity at time of fall, use of mobility aids, and associated environmental hazards [29, 35, 44, 114]. However, the accuracy of these data has been questioned [119, 120], given that many falls are unwitnessed and the challenges for older adults, especially those with cognitive impairment, in accurately recalling and describing the circumstances of falls [121, 122]. Better understanding of the accuracy of fall incident reports may lead to improved approaches towards monitoring and prevention of falls in LTC.

Video capture can provide objective evidence of the characteristics of falls [125, 126, 132] for comparison with incident reports. We recently [132] described the circumstances of 227 real-life falls from 130 individuals captured on video in common areas in two LTC facilities using a structured, validated questionnaire [145, 146]. Using a larger video database of 863 falls in 309 residents, our goal in the current study was to examine the agreement between the characteristics of falls described on incident reports and the characteristics emerging from analysis of video footage of the same falls.

3.2. Methods

3.2.1. Setting.

This study was approved by the Research Ethics Boards of Simon Fraser University and the Fraser Health Authority in British Columbia. Data were collected from two LTC facilities in the greater Vancouver area, affiliated with the Fraser Health Authority: Delta View Life Enrichment Centre, a 312-bed, for-profit facility located in Delta, BC, and New Vista Society Care Home, a 236-bed, not-for-profit facility located in Burnaby, BC. In British Columbia, approximately 35% of LTC facilities are for-profit, while 65% are not-for-profit [147], and the average size of facilities is 87 beds, placing our two facilities in the large category. The average number of hours of care per resident day was 2.72 at New Vista and 3.06 at Delta View (Table 3-1), which is similar to the averages reported previously for LTC in British Columbia [147] and the United States [148, 149]. As described previously [146], residents from these two facilities were similar in demographics and the prevalence of disease diagnoses (Table 3-2) to residents at 35 long-term care facilities owned and operated by Fraser Health.

3.2.2. Fall incident reports.

At both facilities, the occurrence of a fall triggered care personnel (licensed nurses) to complete a structured incident report within 24 hours of the event. The incident report was developed by the research team and care staff at the start of the study, to ensure consistency in the questions and responses, and capture the information common to incident reports in LTC facilities in the Fraser Health Authority. The report documented the time and location of the fall, associated injuries, and information related to the cause of imbalance leading to the fall, the activity at the time of falling, use of mobility aids, and whether the fall was witnessed (Table 3-3). At the onset of this study, we worked with the facilities to review existing incident reports, and modify these to ensure there was a strong match between the incident report and our video analysis questionnaire, in the wording of questions related to cause of imbalance, activity at time of fall, and use of mobility aids, and the specific response categories for these questions.

3.2.3. Video capture of falls.

At the time of admission to the facility, each resident or proxy provided permission for the facility to acquire video footage in common areas, for the purpose of resident safety. These data, along with fall incident reports, were shared as secondary data with our team. Members of our research team communicated daily with care personnel to review incident reports, identify falls occurring in common areas, and retrieve corresponding video footage (Figure 3-1). Both facilities had a total number of 264 cameras that were networked to digital video recorders, which stored video data at a minimal resolution of 640 × 480 pixels and a frame rate of 15 to 30 frames per second.

Between April 2007 and May 2013, we collected and analyzed video footage of 894 reported falls. Thirty-one of these cases (3%) were excluded since they involved the residents appearing to intentionally sit or lay down on the floor, which violates the standard definition of a fall being an “unexpected event” [26]. For the other 863 falls experienced by 309 different residents, 47% (n = 401) occurred in dining areas, 25% (n = 216) occurred in hallways, 24% (n = 211) occurred in lounges, 3.4% (n = 30) occurred in activity rooms and nursing stations, and 0.6% (n = 5) occurred outside the facility.

3.2.4. Data analysis.

A team of three members, who were trained research assistants or graduate students, used a fall video analysis questionnaire (FVAQ) [145] to analyze each video. The FVAQ exhibits good inter- and intra-rater reliability (over 80% agreement, and Cohen's Kappa greater than 0.60) for most questions, including the cause of imbalance leading to the fall, activity at time of fall, and use of mobility aids [145]. These three items were compared to data derived from the fall incident reports. We excluded falls where responses on the incident report were either missing or specified as “don’t know” or “other” (Figure 3-2). While both the incident reports and video analysis considered footwear, floor and lighting condition, we avoided comparing these responses since at least 60% of incident reports were missing these data.

For each question, we report the percentage of agreement between incident reports and video analysis (calculated as the number of cases with the same response divided by the total number of cases) and describe the sources of mismatches (through confusion matrices). We also report the corresponding Cohen’s Kappa coefficient [137]. We follow Landis and Koch [139] recommended interpretation of a Kappa value of >0.8 reflecting “outstanding agreement,” 0.6-0.79 reflecting “good agreement,” 0.4-0.59 reflecting “moderate agreement,” and 0.21–0.40 reflecting “fair agreement.” We also compared witnessed versus unwitnessed falls (through Chi-square tests) in terms of the agreement in responses between the incident reports and video analysis.

3.3. Results

Among 309 participants included in this study, 158 (51%) residents had one fall captured on video, 29 (9%) had three, 16 (5%) had five, and 11 (3.5%) had ten or more. 231 participants had disease diagnoses documented in the incident reports. The mean age was 80.3 years (SD = 11), and 60.6% were women. 32% had Alzheimer's disease, 19.5% had diabetes, 37.7% had hypertension, 11.3% had stroke, and 6.9% had Parkinson's disease. The demographic characteristics and prevalence of disease diagnoses of residents captured falling were similar to the overall population of residents at the two LTC facilities (Table 3-2).

3.3.1. Cause of imbalance.

The cause of imbalance leading to the fall was identified in 552 incident reports. We excluded 198 cases (36%) having a “don’t know” response, and 20 cases (3.5%) with a response of “other” (Figure 3-2). These observations are consistent with previous findings that about 25% of falls in LTC were not adequately documented on incident reports [114, 115]. For the remaining 334 incident reports, the agreement with video analysis on the cause of imbalance was 45.5% (152 cases matched) and the Kappa was 0.25 (Table 3-3). The most common cause of imbalance documented on incident reports was incorrect transfer (47.6%) followed by slip (14.6%) and trip (13.2%). Based on video analysis, similar overall frequencies were observed for incorrect transfer (47.0%) and trip (15.8%). However, the percent of matched cases was only 45% (20 of 44) for falls noted on incident reports as due to tripping, and 58% (92 of 157) for incorrect weight transfer. Falls reported as trips were classified from video analysis as incorrect weight transfer in 17 of 44 cases (Table 3-4). Furthermore, slips were the perceived cause of fewer than 1% of falls from video analysis. Of the 49 falls reported as due to slips, from video analysis 27 were categorized as incorrect weight transfer, and 15 were loss-of-support. There were also fewer cases on incident reports than video analysis of falls due to hit/bump (26 versus 44 cases, with 14 cases reported as incorrect transfer) and loss-of-support with an external object (28 versus 52 cases, with 20 cases reported as incorrect weight transfer, and 15 reported as slips).

3.3.2. Activity at time of fall.

The activity at time of fall was identified in 549 incident reports. We excluded 119 falls (22%) with a response of “don't know” and 9 falls (1.6%) with a response of “other.” Among the remaining 421 falls, the percentage of agreement with video analysis was 45.2% and the Kappa was 0.22 (Table 3-3). From incident reports, the most common activity was walking (53.4%) followed by getting up/rising (21.6%). Sitting down, standing, and seated each represented about 8% of responses. From video analysis, the most common activities were walking (44.2%), standing (25.4%), sitting down (14.4%), and getting up (10.2%). The percent of matched cases was 59% (132 of 225 cases) for walking, and only 16% (15 of 91 cases) for rising. Among falls reported to occur during walking, from video analysis 26% (58 cases) were categorized as standing, and 11% (24 cases) as sitting down (Table 3-5). For falls reported to occur during rising, from video analysis 35% (32 cases) were categorized as walking, 25% (23 cases) were categorized as standing, and 13% (12 cases) were categorized as sitting down.

3.3.3. Use of mobility aids.

787 incident reports indicated whether mobility aids were being used at the time of the fall. We excluded 56 falls (7%) with a response of “don't know.” For the remaining 731 falls, the percentage of agreement with video analysis was 79.5% and the Kappa was 0.59 (Table 3-3). From incident reports, wheelchairs were used in 16% of falls, walkers in 17%, and no mobility aid in 65%. From video analysis, wheelchairs were used in 17% of falls, walkers in 13%, and no mobility aid in 69%. The percent of matching cases was 63% for wheelchairs and 65% for walkers. Of the 126 falls reported to involve walkers, from video analysis 43 (34%) involved no mobility aid (Table 3-6). Similarly, of the 120 falls reported to involve wheelchairs, from video analysis 35 (29%) involved no mobility aid. If a walker was observed from video analysis to be used, it was often correctly noted on the incident report (only 7 of 98 cases reported as no mobility aid). However, the same was not true for wheelchairs: of the 125 falls noted on video to involve wheelchairs, 50 were reported to involve no mobility aid.

3.3.4. Witnessed vs. unwitnessed falls.

The percent of incident reports documenting whether the fall was witnessed was 43% (n = 142) for reports that also described the cause of imbalance, 41% (n = 173) for those describing the activity at time of falling, and 62% (n = 455) for those describing mobility aids (Table 3-7). For each of these outcomes, the portion of falls that were witnessed ranged from 36 - 37%. For cause of imbalance, the agreement between incident reports and video analysis was 53% for witnessed falls, and 30% for unwitnessed falls, a significant difference ($p = 0.01$). For activity at the time of falling, the agreement between incident reports and video analysis was 48% for witnessed falls, and 37% for unwitnessed falls. This difference was not statistically significant ($p = 0.15$). For mobility aids, the agreement between incident reports and video analysis was 81% for witnessed falls, and 72% for unwitnessed falls. This difference just failed to reach statistical significance ($p = 0.07$).

3.4. Discussion

Incident reports are commonly used to monitor the frequency and circumstances of falls among residents in LTC, and guide fall prevention efforts at an individual or population level. Our study highlights the challenges involved in accurately documenting the circumstances of falls through incident reports. We focused on three questions (which match our video analysis questionnaire), concerning the cause of imbalance leading to the fall, the activity at the time of falling, and the use of mobility aids at the time of the fall. We observed fair agreement between incident reports and video analysis for the cause of imbalance (45.3% agreement; Kappa = 0.25) and activity at the time of the fall (45.0% agreement; Kappa = 0.22), and moderate agreement for the use of mobility aids (79.5% agreement; Kappa = 0.59).

With regard to the cause of imbalance, we found that incident reports described 15% of falls as being due to slips, while from video analysis slips accounted for less than 1% of falls. The majority of reported slips were classified on video as loss-of-support or incorrect weight transfer. This may reflect the tendency among both care staff and fallers to rationalize the event as due to an external cause [119, 150, 151]. When compared to video analysis, there was also nearly 50% under-reporting of falls due to loss-of-support and hit/ bump. Among falls observed on video as due to loss-of-support, 82% were associated with an external moving object during transferring (e.g., unlocked wheelchairs, chairs or walkers). These were most often classified on incident report as incorrect weight transfers or slips. Approximately 80% of falls classified from video analysis as due to hit/ bump were caused by aggressive behaviour between two residents. Most cases (63%) were unwitnessed. The agreement between video analysis and incident reports on hit/bump as the cause of imbalance was 71% for witnessed falls and 20% for unwitnessed falls. These results illustrate that aggressive behaviour between residents is a frequent, and often undetected cause of falls in LTC, extending previous observations that about 10% of residents in LTC exhibit aggressive behaviour towards other residents [151].

For the activity at the time of falling, our videos showed that falls often occurred after a sequence of activities (e.g., rising, standing, and walking). This likely increased the challenge for care staff in identifying the primary activity associated with the fall, which our video analyzers discerned through repeated viewing. Falls from standing were nearly three-fold more common based on video analysis than incident reports, with most cases reported as walking. Previous studies have reported that 20 - 40% of falls during transferring [115, 117, 118], but did not separate sitting down from rising. On incident reports, falls were more often described as occurring during rising (22%) than sitting down (9%), while from video analysis, sitting down was more common (14%) than rising (10%). Falls while sitting down were often caused by incorrect weight transfer (e.g., missing the chair) and loss-of-support (e.g., unlocked wheelchair) – unrecognized activities associated with falls.

With regard to mobility aids, we found that approximately 30% of falls noted on incident report to involve walkers or wheelchairs were observed on video to involve no mobility aid. These results complement our previous observation that, in a sample of residents of LTC where 74% were habitual users of walkers or wheelchairs, only 21% of falls occurred while using these mobility aids [132], and Eriksson and colleagues [39] observation that 11% of falls in a dementia ward were associated with forgetting to use mobility aids or difficulty in handling mobility aids.

For falls that were witnessed as opposed to unwitnessed, we found moderately higher agreement between incident reports and video analysis for the cause of imbalance, but no difference for activity at the time of falling and use of mobility aids. The majority of falls in our study (63%) were unwitnessed, which is consistent with previous studies in the community [119, 150] and residential care [114]. The small improvement in agreement may reflect the challenges for witnesses in detecting and describing the circumstances of falls, which tend to be quick events with a duration ranging from 0.7 to 3.0 seconds [120]. During our video analysis sessions, team members were able to repeatedly view the video to identify the best answer to each question [145].

There are important limitations to our study. We examined falls in common areas of two LTC facilities. Accordingly, our results may not apply to falls in private areas (e.g., bedrooms, bathrooms, and stairways) or to healthier older adults living in the community. We did not examine how the accuracy of reporting is affected by modifications to the format of incident report, including instructions and definitions. We focused on questions in the incident report related to the perceived mechanisms of falls, and not resulting injuries or recommended follow-up. We did not examine how agreement between video analysis and incident reports associated with staff or facility characteristics, or the number and characteristics of witnesses to the fall that were interviewed by care staff. These are important questions for future research.

By highlighting the common sources of inaccuracies in fall incident reports, our results indicate opportunities for improving the accuracy of fall reporting in LTC. Care staff under-reported, and should be made aware of the high frequency of falls due to hip/bump (aggression), loss-of-support, and falls while sitting down and standing. Furthermore, care staff greatly over-reported slips as the cause of falls. Careful review of the site of the fall may provide clues on the cause of the fall (e.g., wheelchair brakes that are not locked) and use of a mobility aid (e.g., tipping over a walker). Efforts should be made to seek reliable input from as many witnesses as possible.

While these efforts may bring improvements, the depth of information provided by video capture of the circumstances of falls is difficult to match through witnessing or detective work by care staff. Our results suggest the need for unobtrusive, ethical technologies for detecting and classifying key characteristics of falls in high-risk individuals, and educating care providers on the circumstances of falls at an individual or population level [152, 153]. While there is rapid development of low-cost video networks and wearable sensor technologies for monitoring falls [154, 155], there is a need for standardization of outcomes (that extend beyond fall detection, to characterize how and why the fall occurred) and evaluation of the clinical and cost-effectiveness of these approaches for fall prevention.

Figure 3-1. A fall experienced by a 93 years old woman in long-term care, captured on video.

This woman lost balance by tripping when her right foot collided with her left foot (snapshot C) during walking and turning. While the walker was nearby, she had no contact with it at the time of falling. The fall incident report stated “don’t know” for the cause of the fall, “getting up” as the activity associated with the fall, and “yes” for use of the walker at the time of falling. These images are used with consent from the individual.

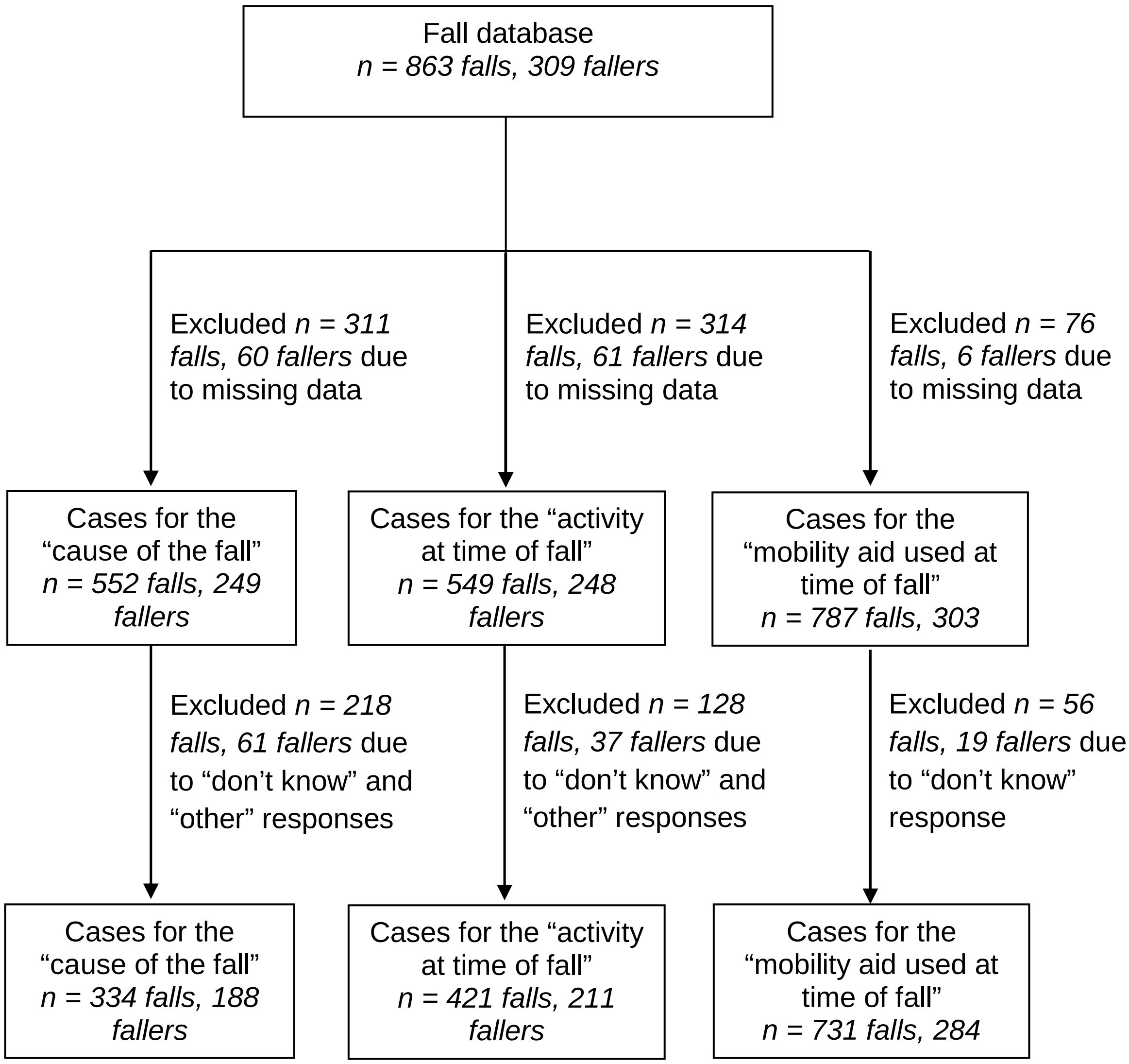

Figure 3-2. Flow chart showing the number of falls (and fallers) included in the analysis for comparison between incident reports and video analysis, and the reasons for excluding specific falls in the analysis.

Table 3-1. Characteristics of New Vista and Delta View long-term care facilities in this study.

Characteristic	New Vista	Delta View
Type of ownership		
Funding model	Non-profit, 100% publically funded residents	For-profit, 70% publically and 30% privately funded residents
Age of facility	39 years	10 years
Size of facility	236 beds	212 beds
Licensing	Licensed by Fraser Health Authority, Province of British Columbia	Licensed by Fraser Health Authority, Province of British Columbia
Staff/resident ratio	1 / 3.1	1 / 2.2
Staffing levels		
Number of licensed physiotherapists	1	1
Number of LPNs - in morning shift	7	5
- in afternoon shift	7	4
- in night shift	2	3
Number of RNs - in morning shift	2	6
- in afternoon shift	2	4
- in night shift	1	1
Number of care aids - in morning shift	27	32
- in afternoon shift	18	32
- in night shift	10	8
Average hours of care per resident day	2.72	3.06
Percentage of resident turnover per year	21%	33%
Average length of stay of residents	3.88 years	3.47 years
Percentage of residents with dementia	47%	58%
Ambulatory status of residents		
Independent	31%	31%
Dependent	69%	69%
Fall rates (rate/1,000 bed-days)	8.9	9.2

LPN: licensed practical nurse; RN: registered nurse.

Table 3-2. Comparison of the characteristics of participants in this study and all residents at New Vista and Delta View long-term care facilities.

	New Vista residents (n=235)	Delta View residents (n=211)	Study participants with documented diagnoses (n=231 residents)
Demographics			
Age (mean, (SD))	83.1 (9.6)	81.7 (11)	80.3 (11)
Female (n, (%))	164 (69.7%)	132 (62.5%)	140 (60.6%)
Disease Diagnoses (n, (%))			
Alzheimer's Disease	45 (19.1%)	59 (28.0%)	32 (29.6%)
Diabetes	46 (19.6%)	55 (26.1%)	45 (19.5%)
Cardiac arrhythmia	7 (3.0%)	6 (2.8%)	7 (3.0%)
Hypertension	117 (49.8%)	107 (50.7%)	87 (37.7%)
Hypotension	1 (0.4%)	2 (0.9%)	1 (0.4%)
Stroke	35 (15.0%)	43 (20.4%)	26 (11.3%)
Parkinson's Disease	10 (4.3%)	8 (3.8%)	16 (6.9%)
COPD	34 (14.5%)	26 (12.3%)	25 (10.8%)

SD, standard deviation; n, absolute number of residents.

Table 3-3. Characteristics of falls described on fall incident reports and determined from video analysis.

Fall characteristic		Incident reports	Video analysis	Matched cases	Percentage of agreement	Cohen's kappa (95%CI)
Category	**Sub-category**	**Frequency (percent)**	**Frequency (percent)**	**Frequency (percent)**		
Cause (n = 334 falls, 188 residents)	**Slip**	49 (14.6%)	2 (0.6%)	1 (2%)	45.3%	0.25 (0.18-0.32)
	Trip/ stumble	44 (13.2%)	53 (15.8%)	20 (45%)		
	Hit/ bump	26 (7.8%)	44 (13.2%)	20 (77%)		
	Dizziness/ fatigue/ loss of consciousness	28 (8.4%)	26 (7.8%)	9 (32%)		
	Incorrect weight transfer	159 (47.6%)	157 (47.0%)	92 (58%)		
	Loss-of-support	28 (8.4%)	52 (15.6%)	10 (36%)		
Activity (n = 421 falls, 211 residents)	**Sitting down/ lowering**	36 (8.6%)	61 (14.4%)	16 (44%)	45.0%	0.22 (0.21-0.23)
	Getting up/ rising	91 (21.6%)	43 (10.2%)	15 (16%)		
	Seated/ wheeling in wheelchair	34 (8.1%)	25 (5.9%)	8 (24%)		
	Walking	225 (53.4%)	186 (44.2%)	132 (59%)		
	Standing	35 (8.3%)	107 (25.4%)	19 (54%)		
Use of mobility aids (n = 731 falls, 284 residents)	**Cane in use**	7 (1.0%)	6 (0.8%)	4 (57%)	79.5%	0.59 (0.53-0.65)
	Wheelchair in use	120 (16.4%)	126 (17.2%)	75 (63%)		
	Walker in use	126 (17.2%)	98 (13.4%)	82 (65%)		
	None	478 (65.4%)	501 (68.5%)	420 (88%)		

CI, confidence interval; n, absolute number of falls.

Table 3-4. **Confusion matrix comparing fall incident reports and video analysis on the cause of imbalances (n = 334 falls). Cells on the highlighted diagonal show the number of falls where there was agreement between responses. Non-diagonal cells show the number of specific mismatches between responses.**

		Incident report on the cause of imbalance (n = 334 falls)						Total
		Slip	Trip/ stumble	Hit/bump	Loss of consciousness	Incorrect weight transfer	loss-of-support	
Video analysis on the cause of imbalance (n = 334 falls)	Slip	1	0	0	0	1	0	2
	Trip/stumble	4	20	1	6	19	3	53
	Hit/bump	1	4	20	2	14	3	44
	Loss of consciousness	1	1	0	9	13	2	26
	Incorrect weight transfer	27	17	2	9	92	10	157
	Loss-of-support	15	2	3	2	20	10	52
Total		49	44	26	28	159	28	334

Table 3-5. **Confusion matrix comparing fall incident reports and video analysis on the activity at time of fall (n = 421 falls). Cells on the highlighted diagonal show the number of falls where there was agreement between responses. Non-diagonal cells show the number of specific mismatches between responses.**

		Incident report on the activity at the time of falling (n = 421 falls)					Total
		Sitting down/ lowering	Getting up/ rising	Seated/ wheeling in wheelchair	Walking	Standing	
Video analysis on the activity at time of falling (n = 421 falls)	Sitting down/lowering	16	12	4	24	5	61
	Getting up/rising	7	15	12	8	1	43
	Seated/ wheeling in wheelchair	3	9	8	3	2	25
	Walking	6	32	7	132	8	185
	Standing	4	23	3	58	19	107
Total		36	91	34	225	35	421

Table 3-6. Confusion matrix comparing fall incident reports and video analysis on the use of mobility aids at the time of falling (n = 731 falls). Cells on the highlighted diagonal show the number of falls where there was agreement between responses. Non-diagonal cells show the number of specific mismatches between responses.

		Incident report on use of the mobility aids at the time of falling (n = 731 falls)				Total
		Cane in use	Wheelchair in use	Walker in use	No mobility aid being used	
Video analysis on the use of mobility aids at the time of falling (n = 731 falls)	Cane in use	4	1	0	1	6
	Wheelchair in use	0	75	1	50	126
	Walker in use	0	9	82	7	98
	No mobility aid being used	3	35	43	420	501
Total		7	120	126	478	731

Table 3-7. Agreement on fall characteristics between video analysis and incident reports for witnessed falls versus unwitnessed falls.

Fall characteristic	Number of Falls	Witnessed falls	Unwitnessed falls	p-value from Chi-square test
Cause of imbalance	n = 142	53 (37%)	89 (63%)	
Agreement with video analysis		52.8%	30.3%	**p = 0.012**
Activity at the time of falling	n = 173	62 (36%)	111 (64%)	
Agreement with video analysis		48.4%	36.9%	p = 0.15
Use of mobility aids at the time of falling	n = 455	162 (36%)	293 (64%)	
Agreement with video analysis		81%	72%	p = 0.07

Chapter 4. Risk factors associated with head impact during falls in older adults in long-term care

Abstract

Background: More than 60% of traumatic brain injuries in older adults are caused by falls. A barrier to prevention is lack of objective evidence on the factors that influence the risk for impact to the head in the event of a fall. We examined biomechanical factors (from the analysis of real-life falls captured on video) and physiological factors (acquired from health records) on the risk of head impact during falls in two long-term care (LTC) facilities.

Methods: Between April 2007 and June 2014, we video-captured 520 falls experienced by 160 residents (mean age = 81 (SD = 9); 62% female). Each fall was analyzed by a 3-member team using a validated questionnaire to determine whether impact occurred to the head or hand, cause of imbalance, activity at time of fall, fall direction, and use of mobility aids. We also collected information related to physical and cognitive function, disease diagnoses, and use of medications from the computerized Minimum Data Set system. We used a Generalized Estimating Equation (GEE) model to calculate the odds ratio (OR) for head impact associated with the various factors.

Results: Head impact occurred in 32.7% of falls. Compared to men, women showed higher risk to impact their head during a fall (OR = 2.15, 95% CI 1.40-3.29). Impaired vision was associated with higher odds of head impact (2.02, 1.34-3.04). Residents with intact to mild cognitive impairment were at higher risk for head impact (2.78, 1.52-5.00), compared to participants with moderate to severe cognitive impairment. Head impact was 2.28-fold (1.47-3.54) more likely to occur during falls from walking than falls while performing other activities, and more likely to occur in falls with initially directed forward and landing forward. Walking was more common to occur in women, and in individuals who were less cognitively impaired, and relatively independent in performing daily activities. Hand impact was not effective in reducing the occurrence of head impact. In 61% of forward falls, residents rotated to land sideways or backwards, which associated with a decreased odds of head impact (0.36, 0.15-0.86).

Conclusions: Our results provide insight on how biomechanical and physiological factors influence the risk for head impact during falls in LTC. Women and individuals with better cognitive function were at higher risk of head impact, possibly due to their tendency of falling while walking, and forward falling and landing. Poor vision was associated with a more than 2-fold increased odds for head impact, likely via its effect on the coordination of safe landing responses. Our results suggest that treatment of visual impairment, and exercise training may reduce the likelihood for impact and injury to the head from falls in the LTC environment.

4.1. Introduction

Falls cause more than 65% of traumatic brain injury (TBI) in older adults [9, 10]; about one-quarter of these cases occur in long-term care (LTC) facilities [10]. The mortality rate in older adults who are admitted to hospital with TBI is approximately 30% [11, 12]. Furthermore, the incidence of fall-related TBI has increased 2-3 folds over the past few decades, especially in the LTC environment [10, 78, 156]. The reasons for this trend are not fully understood, with some suggesting that it may be due to greater fall rates [157], and others suggesting that it may be due to increased use of anticoagulant agents that elevate the risk of intracranial hematomas following head impact from a fall [85, 87]. A recent study found that older adults on anticoagulant had nearly 2-fold increased risk for TBI [85].

Any falls from standing height or lower can potentially cause brain injury if a direct impact occurs to the head [56, 88, 89]. Therefore, understanding the factors that separate falls that result in head impact from falls that do not, may lead to improvements in the prevention of TBI. Research to date on fall protective mechanisms has been limited primarily to laboratory studies with young adults, who tend to universally avoid head impact during falls, through protective strategies such as use of the outstretched arm(s) to arrest the fall, trunk flexion and rotation during descent, and control of the neck muscles during descent and landing [48, 49, 98, 111]. The frequency and characteristics of falls have been shown to associate with a variety of physiological factors, such as age [55], sex [111], cognitive demand [105, 158], muscle strength [111, 159], vision [60, 105], chronic disease [108, 160], and psychotropic medications [161], and with biomechanical and situational characteristics of the fall, such as the cause of imbalance, activity at time of fall, and direction of the fall [10, 146]. However, our understanding of fall mechanisms among older adults is currently based on interviews or self-reports of fallers [119]. Furthermore, few efforts have been made to examine the mechanisms of falls in older adults in the complex LTC environment [162, 163].

Video capture of real-life falls provides objective evidence on the mechanisms of falls in the LTC setting [132, 146]. Recently, we used a dataset of 227 falls experienced by 133 residents in LTC to examine the prevalence and biomechanical factors associated with head impact [146]. We reported that 37% of falls resulted in head impact. We also found that the probability for head impact was increased by falling forward, and was not reduced by hand impact.

In the present study, we use a larger sample of 520 falls in 160 participants, to examine how age, sex, and physiological factors (including physical and cognitive function, chronic diseases, and medications) influence fall mechanisms and the risk for head impact. Our specific research questions were: (1) What are the unadjusted associations between head impact and biomechanical factors of the fall? (2) What are the unadjusted associations between head impact and physiological factors of the faller? (3) What are independent biomechanical and physiological risk factors for head impact? (4) What are the associations between biomechanical and physiological factors leading to head impact?

4.2. Methods

4.2.1. Participants and setting.

Between April 20, 2007 and June 30, 2014, we collected and analyzed video footage of 1215 falls experienced by 398 residents in two LTC facilities (Figure 4-1). For the purposes of this study, we excluded cases due to (a) lack of consent to access medical records (n = 498 falls by 211 residents), (b) no MDS records available (n = 87 falls by 15 residents), and (c) no MDS records data acquired within 6 months prior to the fall (n = 110 falls in 12 residents). This resulted in a study sample of 160 participants who experienced a total of 520 falls.

New Vista Society Care Home is an intermediate care facility with 236 beds, located in Burnaby, BC. Delta View Life Enrichment Centre is a multi-level residential care facility with 312 beds, located in Delta, BC. New Vista had a network of 48 digital cameras, and Delta View had 216. All cameras were located in common areas (e.g., dining rooms, lounges, activity rooms, and hallways). The videos were stored at a recording rate of 15 to 30 frames per second and a resolution of at least 640 × 480. The study was approved by the research ethics boards of Simon Fraser University and Fraser Health Authority. At the time of admission to the LTC facility, each resident or proxy provided permission to the facility to acquire video footage in common areas for safety purposes. These data were shared as secondary data with our research team. All participants in this study provided written consent for us to access their health records.

4.2.2. Fall video analysis.

Each fall video was analyzed by three evaluators, who sought consensus of the best available answers to a Fall Video Analysis Questionnaire (FVAQ) [145]. In the present study, we focused on questions related to whether impact occurred to the head, the cause of imbalance, activity at the time of the fall, initial fall direction, landing configuration, whether impact occurred to the hand(s) or forearm(s), and use of mobility aids at time of fall. Tests of inter-rater and intra-rater reliability showed more than 80% agreement and a Cohen *k* value of greater than 0.67 for all these items [145]. Since falls due to slip and trip and falls during walking have been shown to increase the risk of injury [10, 14, 27, 47], we categorized the cause of imbalance into “slip and trip vs. all other causes” and the activity at time of fall into “walking vs. all other activities”. Based on our previous finding that falling forward and landing forward were associated with the risk of head impact [146], we categorized initial fall direction into “falling forward vs. other directions”, and landing configuration into “landing forward vs. other configurations”. Due to a high proportion of falls changing the direction from initial falling to landing [146], we categorized body rotation into “forward falling to sideways or backward landing vs. no rotation (forward falling to forward landing).

4.2.3. Clinical data from the Minimum Data Set (MDS).

We characterized the physiological status of participants based on information from the Minimum Data Set (MDS 2.0, interRAI Corporation 1999) which is a comprehensive observational assessment of functional, medical, psychological, and cognitive status of residents in LTC [164, 165]. We focused on variables from the MDS shown previously to associate with falls and fall-related injuries [66, 166], including: (1) age; (2) sex; (3) Activities of Daily Living (ADL) self-performance scale, [The ADL scale includes four items – eating, locomotion, toileting, and personal hygiene [167] with scores ranging from 0 (independent) to 6 (total dependence)]; (4) Cognitive Performance Scale (CPS), [The CPS includes five items: short-term memory, daily decision making, ability to make self understood, eating self-performance, and comatose status [168], with scores ranging from 0 (intact) to 6 (very severe impairment)]; (5) vision, [Vision ranges from 0 (adequate) to 4 (severely impaired)]; (6) diseases diagnoses, [Disease diagnoses include diabetes, Alzheimer’s disease, hypertension, and stroke]; (7) use of medications, [Medications include antipsychotic, antianxiety, antidepressant, hypnotic, diuretic, and analgesics]. MDS was assessed quarterly and annually (full assessment). We only selected data that were completed within 6 months prior to the fall. The average time lag was 2.1 (SD = 1.6) months.

4.2.4. Statistical analysis.

We used a General Estimating Equation (GEE) model to examine the association between physiological factors and the occurrence of head impact and fall mechanisms, to account for the potential correlation among repeated falls by a given resident. Participant ID and frequency of falls per participant were considered as subject variable and repeated variable in the GEE model. Since our outcome variables were head impact (a binary variable) and the dichotomized fall mechanisms (Table 4-4), we used the logistic link function in GEE. We categorized age into lowest quartile - Q1 (<77 years), highest quartile - Q3 (>87 years), and two middle quartiles - Q2 (77-87 years). Following the approach used by others [47, 66], we dichotomized the ADL scores into 'independent' (0-2) versus 'dependent' (3-6), CPS scores into 'intact to mild impairment' (0-2) versus 'moderate to severe impairment' (3-6), and vision scores into 'adequate' (0) versus 'impaired' (1-4). Sex, disease diagnoses, and use of medications were treated as dichotomous variables.

We first examined univariate associations between the occurrence of head impact and each of the physiological factors and biomechanical variables (fall mechanisms). We report frequencies of head impact for all levels of each explanatory variable. We also report odds ratios (ORs) and corresponding 95% confidence intervals (CIs) for the comparisons between levels. We then constructed multivariate models to separately examine the association (ORs and 95% CIs) of (i) physiological factors and (ii) biomechanical variables and the occurrence of head impact. In each model, we included explanatory variables that had $p \leq 0.1$ in univariate associations. Finally, we examined the associations between physiological and biomechanical factors that were associated with head impact using GEE univeriate model. All statistical analyses were conducted using SPSS version 22 (IBM Corporation, Armonk, NY) with the significance level set at $\alpha = 0.05$.

4.3. Results

4.3.1. Participant characteristics.

Among the 160 participants included in this study, 74 (46.3%) residents had one fall captured on video, 33 (20.6%) had two, 15 (9.4%) had three, 16 (10%) had four, 5 (3.1%) had five, and 17 (10.6%) had six or more. The mean age of participants was 81.7 (SD = 9.5) years, and 62.5% were women (Table 4-1). Based on MDS data, 29.4% had Alzheimer's disease, 21.3% had diabetes, 40.0% had hypertension, 11.3% had stroke, and 2.5% had Parkinson's disease. The mean ADL performance score was 3.3 (SD = 1.5), and 63% of participants were dependent in ADL performance. The mean cognitive performance score (CPS) was 3.8 (SD = 1.5), and 74% of participants had moderate to severe cognitive impairment. 45% of participants used antipsychotics, 45.6% used antidepressants, and 51.2% used analgesics. These demographics and health information were similar to those of residents in New Vista and Delta View long-term care facilities (Table 4-1).

4.3.2. Prevalence of head impact and injuries.

Among the 520 falls analyzed, head impact occurred in 32.7% of cases (n = 170). The head impacted the ground in 64% of falls (n = 109), a wall in 12% (n = 20) and furniture in 24% (n = 41). 68% (n = 116) of falls involving head impact were from standing height, and 32% (n = 54) were from lower than standing height (e.g., a fall from a chair or wheelchair). In 84% of falls in which the head struck the ground, the flooring was vinyl or linoleum, whereas in 15%, it was carpet. Among falls involving head impact (n = 170), 29.4% (n = 50) were documented with injuries in the incident reports. Among these, 48% (n = 24) were abrasions or lacerations, 28% (n = 14) were hematoma, 14% (n = 7) were pain, and 10% (n = 5) were bruises or tenderness. No concussions were documented in incident reports.

4.3.3. Physiological factors and the risk of head impact.

In the univariate analyses (Table 4-2), sex, ADL performance, cognitive performance, vision, and use of antidepressants were significantly associated with head impact. In women, 40% of falls (119 of 295) resulted in head impact, while only 23% (51 of 225) caused head impact in men. Among individuals with impaired vision, 42% of falls (91 of 218) resulted in head impact, while in those with adequate vision, 26% (76 of 302) resulted in head impact (Table 4-2). The OR for head impact was 2.37-fold (95% CI 1.58 – 3.55) greater for women, and 2.01-fold (1.38 – 2.92) greater for participants with impaired vision. Independent ADL performance was associated with increased odds of head impact (OR 1.54, 95% CI 1.01 – 2.33). Intact to mild cognitive impairment was associated with an increased odds for head impact (2.63, 1.61– 4.35). Use of antidepressant was associated with a decreased odds for head impact (0.63, 0.43 – 0.91). Age, diagnosis of hypertension, Alzheimer's disease, or stroke, and the use of antipsychotic, antianxiety, hypnotic, diuretic, or analgesics were not associated with the occurrence of head impact.

In the multivariate analysis of physiological predictors (Table 4-2), sex, vision, and cognitive performance remained associated with head impact after adjustment for other physiological factors. Falls in women were more likely to result in head impact than falls in men (2.15, 1.40 – 3.29). Participants with impaired vision were 2.02 times (1.34 – 3.04) more likely to suffer head impact compared to those with adequate vision. Intact to mild cognitive impairment was associated with an increased OR (2.78, 1.52 – 5.00) for head impact, compared to moderate to severe cognitive impairment. In the multivariate analysis, there were no significant differences for the odds of head impact between different age groups, between participants who used antidepressant versus who did not, and between participants who were dependent versus independent in ADL performance.

4.3.4. Fall mechanisms and the risk of head impact.

In the univariate analyses (Table 4-3), the cause of imbalance, activity at time of fall, initial fall direction, landing configuration, hand impact were found to significantly associate with the probability for head impact. The OR for head impact was 2.17-fold (1.27 – 3.72) greater for falls due to slip and trip, 2.6 -fold (1.76 – 3.82) greater for falls during walking, 2.48-fold (1.57 – 3.89) greater for falls initially directed forward than falls in other direction, and 3.5-fold (1.96 – 6.25) greater for falls involving a forward landing configuration than other configuration. In 61% of falls initially directed forward (59 of 96), the individuals rotated to land sideways or backward, which was associated with a decreased odds of head impact (0.36, 0.15 – 0.86). Hand impact was associated with an increased odds for head impact (1.54, 1.04 – 2.29), compared to no hand impact. Among the 520 falls, 12% (n = 62) were due to 'slip and trip' (only two cases of which involved slipping), and 48.4% of cases involved head impact (30 of 62). 33% of falls occurred during walking (n = 171), including 89% of 'slip and trips.'18% of falls (n = 96) were initially directed forward and 10% (n = 54) involved forward landing configurations. Among falls during walking, 29% were initially directed forward and 19% involved a forward landing configuration. Hand impact occurred in 64% of falls (n =

335). In the multivariate analysis (Table 4-3), activity at time of fall and landing configuration were independently associated with head impact. Falls during walking were associated with 2.28-fold (1.47 – 3.54) greater odds for head impact, compared to other activities. Landing forward was associated with 2.14-fold (1.11 – 4.13) greater odds for head impact, compared to other landing configurations. Initial fall direction just failed to reach significance (p = 0.072), and there was no significant association between head impact and cause of imbalance and hand impact.

4.3.5. Physiological factors and fall mechanisms.

Activity at time of fall was associated with sex, with women being 1.91 times (1.28 – 2.85) more likely than men to fall while walking (Table 4-4). There was no significant association between sex and cause of imbalance, initial fall direction, landing configuration, body rotation, and hand impact. Compared to participants with dependent ADL performance, participants with independent ADL performance were 2.15 times (1.41 – 3.26) more likely to fall during walking, 1.75 times (1.07 – 2.84) more likely to fall initially forward, and 2.14 times (1.18 – 3.88) more likely to have a forward landing configuration. However, ADL performance did not associate with cause of imbalance, body rotation, or frequency of hand impact. Participants with intact to mild cognitive impairment were 1.84 times (1.11 – 3.07) more likely to fall during walking, 2.62 times (1.51 – 4.56) more likely to fall initially forward, and 1.98 times (1.00 – 3.98) more likely to land forward, when compared to participants with moderate to severe cognitive impairment. Neither cognitive performance nor vision associated with cause of imbalance, body rotation, or frequency of hand impact. None of the examined fall mechanisms were associated with age.

4.4. Discussion

Based on the analysis of 520 real-life falls captured on video and the medical records of 160 participants, we examined how physiological and biomechanical factors associate with head impact during falls among older adults in long-term care. We found that 33% of all falls in this setting resulted in head impact. The typical individual who is at particularly risk for head impact during a fall is female, relatively intact in cognitive performance and independent in performing daily activities, but suffers from impaired vision. Risk for head impact did not associate with age, or with the disease diagnoses or medications we examined.

Our results provide insight on the reasons for these observations, in terms of two fall mechanisms that were associated with risk for head impact: the activity at the time of falling, and the direction of the fall. Head impact was 2.3-fold more likely to occur during falls from walking than falls while performing other activities. These falls were more likely to occur in women than men, and in individuals who were less cognitively impaired, and relatively independent in performing daily activities. Head impact was more likely during falls initially directed forward, and 2.1-fold more likely for forward landing configurations, when compared to other fall directions. Again, forward falls were more likely to occur in individuals who were less cognitively impaired, and relatively independent in performing daily activities.

We were surprised to observe that the odds for head impact were greater for individuals who were relatively intact in cognition and independent in ADL performance. This appears inconsistent with previous studies that reported higher risk for fall-related head trauma in people with cognitive impairment, versus those with intact cognition, living in the community [2, 169]. We wondered whether this might relate to our cut-point in dividing CPS scores, but this appears unlikely - in our sample, 15 of the 520 falls occurred in individuals with a CPS score of 0 (intact cognition), and 47% (n = 7) of these falls resulted in head impact (Table 4-5). Apparently the increased risk for head impact posed by these falls was not entirely offset by intact cognition, or physical function. While participants with intact to mild cognitive impairment in this study had a 2.63-fold increased odds to suffer head impact compared to those with moderate to severe impairment, they also fell less often over the observation period (1.8 versus 3.7 video-captured falls per person), and consequently had lower rates of head impact due to falls (0.9 versus 1.1 falls with head impact per person).

Our results suggest that the reason why participants with intact to mild cognitive impairment and independence in ADL performance suffered higher risk for head impact is situational, probably due to their tendency to fall during walking, and fall forward and land forward. In comparison, participants with severe cognitive impairment and greater dependence in ADL performance were more likely to fall during activities such as transferring (rising or lowering), seated, or standing, and land in backward or sideways directions with decreased risk for head impact. In line with our finding, Tinetti et al [170] found that fall-related injuries in nursing home are more common among residents who are more independent and less depressed. They also found that falls while rising were less likely to result in any injury than falls from standing or walking, supporting that the circumstances of falls (e.g., type of activity) is associated with injury risk. The effect of ADL performance on head impact is not significant in the multivariate analysis, which may be due to confounding factors such as cognitive performance. We found that 85% of participants with moderate to severe cognitive impairment were dependent in ADL performance. This is consistent with previous finding that older adults with cognitive impairments tend to have poor physical performance [171].

The finding that falling while walking was associated with higher risk of head impact than falling during other activities is in agreement with previous studies showing high injury rates in falls during walking [10, 27, 47]. One explanation may relate to fall direction, as discussed above. Another reason may relate to the higher frequency and intensity of physical activity predisposing to falls that result in head impact [157, 172, 173]. We did not examine the physical activity level of participants, so its association with risk for head impact is unclear. Physical activity is recommended for older adults to maintain mobility and general health [174], but clearly the goal must be "safe mobility."

We found that, when compared to men, women had a higher risk for head impact when falling. This is consistent with a study showing that older women suffered 30% greater rates than men of head/neck injury from falls in emergency visits [175]. Tinetti et al [2] also found that older women experienced 1.8 times greater odds of fall-related injuries than men in the community. In the current study, we observed that women tended to fall more often during walking than men, which may be one factor leading to the higher risk of head impact. Previous studies have found that women exhibit reduced hip extension [176] and decreased toe elevation [177] during walking when compared to men, and this may contribute to our observed trends. Impaired vision was independently associated with a 2-fold increased odds of head impact. It was not clear from our results why impaired vision affected the probability for head impact, as we found no significant associations between vision and other potentially explanatory fall mechanisms. It is reasonable to expect that vision influences the ability to accurately survey environmental features [178, 179], and coordinate safe landing responses (e.g., hand placement and timing). However, further in-depth examination is needed to test this association.

Surprisingly, the probability for head impact was not associated with impact to the hand(s), which occurred in 65% of all falls, with the majority (88%) in forward falls. Furthermore, there were no associations between physiological status of fallers and the tendency for upper limb impact. This raises the question of whether upper limb fall arrest, so seemingly relevant to the avoidance of head impact in younger adults [48, 49] is lost as an effective protective response in older adults in LTC, likely due to its high strength demands [159]. While we can only promote efforts to regain this ability, under this scenario, older adults may need to rely on alternative strategies for avoiding head impact during a fall. One strategy, observed in 61% of falls initially directed forward, was to rotate to land sideways or backward. This decreased the odds of head impact by 2.7 fold. Another factor worth further exploration is contraction of the trunk and neck muscles to stabilize the position of the trunk and head during impact, which appeared to be especially important to avoiding head impact during backward falls [98].

We found that those with higher levels of cognitive impairment were just as likely to rotate during descent and impact the hands, suggesting that these fall protective responses remain relatively intact even in advanced dementia. This may reflect a relatively deep level of “hard-wiring” of these responses, or a tendency in real life for attention to be quickly diverted to postural responses, even in the face of reduced cognitive reserves [105, 110, 158].

Our study suggests the need for improvement in the prevention and reduction of the severity of head impact in older adults in LTC environment. Our results also raise questions regarding potential under-diagnosis of fall-related brain injury in LTC. Despite one third of falls resulted in head impact, only 29% of those reported minor injuries such as bruises or laceration, no concussions were documented. This may reflect the challenges of separating the cognitive effects of head injury from baseline dementia in LTC [180], and suggest the need to consider computed tomography (CT) scanning to detect brain injuries for fall-related hospital admission from long-term care. Regarding the prevention of head impact, older adults should regularly undergo eye examination. Proper vision correction (e.g., refractive error correction, cataract extraction) may prevent injurious falls [181]. Upper extremity strength training in older adults may help improve their ability to arrest a fall [159], and neck and core muscle strength training may help avoid head impact [98]. Another potential target for exercise programs is training in body rotation during descent [112], which we found to be both common and effective in preventing head impact during falls. The feasibility of such exercise programs in LTC needs to be further explored. In lieu of evidence on the feasibility and effectiveness of these programs, a promising approach to preventing fall-related head injuries in LTC is environmental modification. Of particular interest is compliant flooring, a passive form of protection that can attenuate impact forces to the head by up to 50% [182], without affecting mobility and balance.

There are important limitations to this study. Our outcome variable was head impact, which is a primary determinant of risk for head injury. We did not include head injuries in our analysis or measures of impact severity (e.g., impact configuration and velocity). We only examined falls in common areas of two LTC facilities. Accordingly, our results may not apply to falls in private areas (e.g., bedrooms, bathrooms, and stairways) or to healthier older adults living in the community. Furthermore, we acquired data on the physiological status of participants from MDS, which lacks detailed information on potentially relevant factors such as executive function, visual acuity, contrast sensitivity, and upper limb strength. We did not measure the frequency and intensity of physical activities of our participants, so we were unable to determine whether risk for head impact (or other fall mechanisms) was influenced by the physical activity level.

4.5. Conclusion

This study provides the first evidence of how physiological factors influence fall mechanisms and the risk of head impact during falls in older adults in LTC. Poor vision caused about a 2-fold increase in odds for head impact, likely via its effect on the coordination of safe landing and hand arresting responses. Sex was a significant predictor of head impact, with women being over 2 times more likely to impact their head during a fall, probably due to their tendency of falling during walking. Residents with mild cognitive impairment and independence in their ADL performance were more likely to suffer head impact, due in part to their tendency of forward falling and land forward. Hand impact was not effective in preventing head impact, while a tendency of body rotation from forward to sideways decreased the risk for head impact. Our results suggest that, for residents of LTC, treatment of visual impairment and deficits in muscle strength may reduce the likelihood for impact and injury to the head from falls.

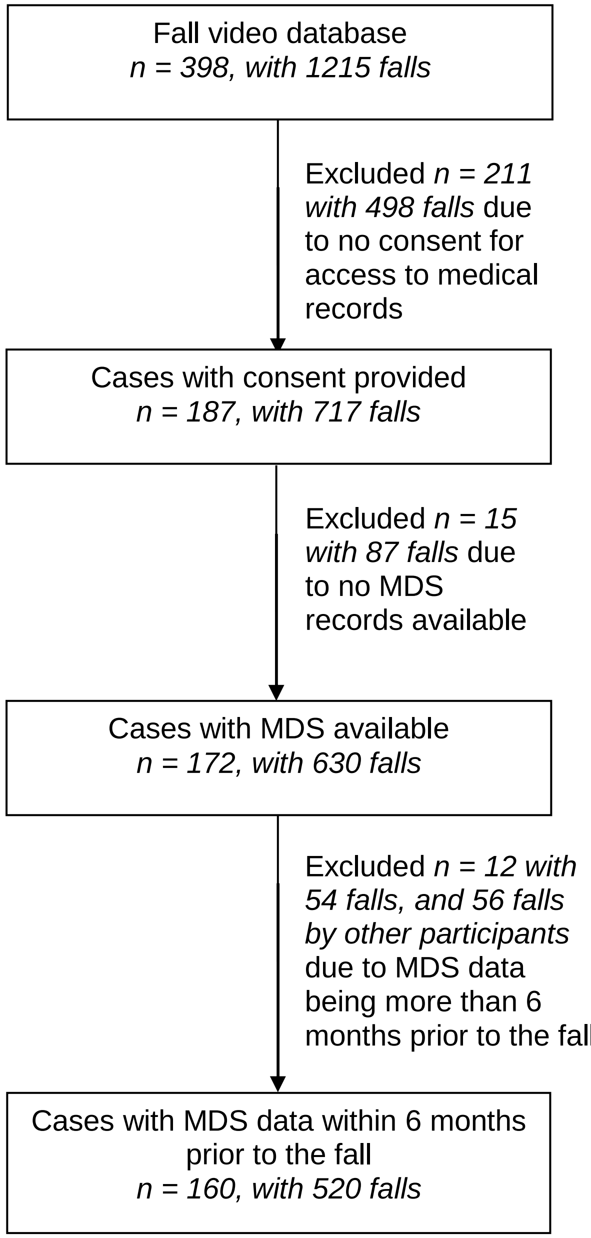

Figure 4-1. Flow chart of sample selection (participants and falls) in this study.

Table 4-1. Comparison of the characteristics of participants in this study and the current residents at New Vista and Delta View long-term care facilities.

	New Vista residents (n=235)	Delta View residents (n=211)	Participants in this study (n=160)
Demographics and health condition			
Age (mean, (SD))	83.1 (9.6)	81.7 (11)	81.7 (9.5)
Female (n, (%))	164 (69.7)	132 (62.5)	100 (62.5)
Dependent ADL performance (n, (%))	163 (69.4)	146 (69.3)	101 (63.1)
Moderate to severe cognitive impairment (n, (%))	187 (79.6)	175 (83)	119 (74.4)
Impaired vision (n, (%))	78 (33.2)	81 (38.4)	63 (39.4)
Disease Diagnoses (n, (%))			
Alzheimer's Disease	45 (19.1)	59 (28.0)	47 (29.4)
Diabetes	46 (19.6)	55 (26.1)	34 (21.3)
Cardiac arrhythmia	7 (3.0)	6 (2.8)	8 (5.0)
Hypertension	117 (49.8)	107 (50.7)	64 (40)
Hypotension	1 (0.4)	2 (0.9)	2 (1.2)
Stroke	35 (15.0)	43 (20.4)	18 (11.3)
Parkinson's Disease	10 (4.3)	8 (3.8)	4 (2.5)
COPD	34 (14.5)	26 (12.3)	19 (11.9)
Use of Medications (n, (%))			
Antipsychotic	88 (37.4)	75 (35.5)	72 (45)
Antianxiety	51 (21.7)	36 (17.1)	30 (18.8)
Antidepressant	110 (46.8)	87 (41.2)	73 (45.6)
Hypnotic	58 (24.7)	33 (15.6)	23 (14.4)
Diuretic	69 (29.4)	60 (28.4)	36 (22.5)
Analgesics	113 (48.1)	109 (51.7)	82 (51.2)

SD, standard deviation; n, absolute number of residents.

Table 4-2. Univariate and Multivariate analyses for physiological factors associated with the risk of head impact

Variables being compared	Number (%) of falls		Univariate analysis		Multivariate analysis	
	Head impact	No head impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
§ Age						
Q1 (<77) vs.	48 (36.6)	83 (63.4)	1.08 (0.65 – 1.78)	0.755	1.21 (0.72 – 2.00)	0.471
Q2 (77-87) vs.	70 (29.4)	168 (70.6)	0.74 (0.47 – 1.19)	0.191	1.06 (0.65 – 1.69)	0.811
Q3 (>87) (reference)	51 (34.2)	98 (65.8)				
§ Female vs.	119 (40.3)	176 (59.7)	2.37 (1.58 – 3.55)	**< 0.001**	2.15 (1.40 – 3.29)	**< 0.001**
Male (reference)	51 (22.7)	174 (77.3)				
§ Impaired vision vs.	91 (41.7)	127 (58.3)	2.01 (1.38 – 2.92)	**< 0.001**	2.02 (1.34 – 3.04)	**< 0.001**
Adequate vision (reference)	79 (26.2)	223 (73.8)				
§ ADL performance						
Independent vs.	49 (40.1)	73 (59.9)	1.54 (1.01 – 2.33)	**0.047**	1.11 (0.66 – 1.89)	0.684
Dependent (reference)	121 (30.4)	277 (69.6)				
§ Cognitive impairment						
Intact to mild vs.	38 (52.0)	34 (48.0)	2.63 (1.61– 4.35)	**< 0.001**	2.78 (1.52 – 5.00)	**< 0.001**
Moderate to severe (reference)	132 (29.5)	316 (70.5)				
Hypertension vs.	66 (35.1)	122 (64.9)	1.17 (0.80 – 1.72)	0.413		
No (reference)	104 (31.3)	228 (68.7)				
Alzheimer's disease	77 (31.2)	170 (68.8)	0.88 (0.61 – 1.28)	0.509		
No (reference)	93 (34.1)	180 (65.9)				
Stroke	22 (42.3)	30 (57.7)	1.55 (0.86 – 2.80)	0.146		
No (reference)	148 (31.6)	320 (68.4)				

Variables being compared	Number (%) of falls		Univariate analysis		Multivariate analysis	
	Head impact	No head impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
Use of medication						
Antipsychotic	73 (29.3)	176 (70.7)	0.75 (0.52 – 1.09)	0.132		
No (reference)	97 (35.8)	174 (64.2)				
Antianxiety	27 (26.2)	76 (73.8)	0.67 (0.41 – 1.08)	0.103		
No (reference)	143 (34.3)	274 (65.7)				
§ Antidepressant	73 (27.5)	192 (72.5)	0.63 (0.43 – 0.91)	**0.014**	0.75 (0.50 – 1.13)	0.167
No (reference)	97 (38.0)	158 (68.0)				
Hypnotic	29 (41.4)	41 (58.6)	1.53 (0.91 – 2.57)	0.108		
No (reference)	141 (31.3)	309 (68.7)				
Diuretic	46 (36.5)	80 (63.5)	1.22 (0.79 – 1.89)	0.371		
No (reference)	124 (31.5)	270 (68.5)				
Analgesics	82 (32.5)	170 (67.5)	0.96 (0.66 – 1.40)	0.838		
No (reference)	88 (32.8)	180 (67.2)				

Q1 lowest quartile, Q2 two middle quartiles, Q3 highest quartile; § variables that were selected to the multivariate analysis.

Table 4-3. Univariate and Multivariate analyses for fall mechanisms associated with the risk of head impact

Variables being compared	Number (%) of falls		Univariate analysis		Multivariate analysis	
	Head impact	No head impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
§ Cause of imbalance						
Slip and trip vs.	30 (48.4)	32 (51.6)	2.17 (1.27 – 3.72)	**0.005**	0.97 (0.51 – 1.84)	0.913
Other causes (reference)	140 (30.6)	317 (69.4)				
§ Activity at time of fall						
Walking vs.	80 (46.8)	91 (53.2)	2.60 (1.76 – 3.82)	**< 0.001**	2.28 (1.47 – 3.54)	**< 0.001**
Other activities (reference)	90 (25.8)	259 (74.2)				
§ Initial fall direction						
Forward vs.	48 (50.0)	48 (50.0)	2.48 (1.57 – 3.89)	**< 0.001**	1.65 (0.96 – 2.84)	0.072
Other directions (reference)	122 (28.8)	301 (71.2)				
§ Landing configuration						
Forward vs.	32 (59.3)	22 (40.7)	3.50 (1.96 – 6.25)	**< 0.001**	2.14 (1.11 – 4.13)	**0.023**
Other configurations (reference)	138 (29.7)	327 (70.3)				
Body rotation						
From forward to sideways or backward vs.	24 (40.3)	35 (59.3)	0.36 (0.15 – 0.86)	**0.021**		
No rotation (reference)	24 (64.9)	13 (35.1)				
§ Hand impact vs.	121 (36.1)	214 (63.9)	1.54 (1.04 – 2.29)	**0.033**	1.12 (0.74 – 1.72)	0.591
No hand impact (reference)	49 (26.6)	135 (73.4)				
Use of mobility aids vs.	61 (33.0)	124 (67.0)	1.01 (0.69 – 1.48)	0.960		
None (reference)	109 (32.5)	226 (67.5)				

§ variables that were selected to the multivariate analysis; Body rotation was not included in the multivariate analysis to avoid the multicollinearity with initial fall direction and landing configuration.

Table 4-4. Associations between physiological factors and fall mechanisms.

	Odds Ratio (95% CI)					
	Cause of imbalance	**Activity at time of fall**	**Initial fall direction**	**Landing configuration**	**Body rotation during descent**	**Hand impact**
	Slip and trip vs. Other causes	Walking vs. Other activities	Forward vs. Other direction	Forward vs. Other configuration	Forward to others vs. No rotation	Yes vs. No
Age						
Q3 (>87) vs. Q2 (77 - 87)	0.88 (0.45 – 1.72)	0.90 (0.57 – 1.43)	1.01 (0.58 – 1.75)	0.80 (0.38 – 1.64)	1.05 (0.34 – 3.27)	1.00 (0.48 – 1.12)
Q3 (>87) vs. Q1 (<77)	1.13 (0.58 – 2.21)	1.10 (0.70 – 1.76)	0.60 (0.35 – 1.02)	1.26 (0.61 – 2.60)	1.48 (0.52 – 4.25)	1.00 (0.63 – 1.59)
Sex						
Female vs. Male	1.47 (0.83 – 2.61)	1.91 (1.28 – 2.85) *	1.25 (0.78 – 2.00)	1.04 (0.58 – 1.89)	0.71 (0.29 – 1.69)	0.82 (0.56 – 1.21)
Vision						
Adequate vs. Impaired	0.59 (0.33 – 1.06)	0.87 (0.60 – 1.27)	1.23 (0.79 – 1.93)	1.27 (0.72 – 2.24)	0.66 (0.28 – 1.52)	0.90 (0.63 – 1.31)
ADL performance						
Independent vs. Dependent	1.71 (0.96 – 3.05)	2.15 (1.41 – 3.26) *	1.75 (1.07 – 2.84) *	2.14 (1.18 – 3.88) *	0.57 (0.24 – 1.40)	1.40 (0.90 – 2.17)
Cognitive impairment						
Intact to mild vs. Moderate to severe	1.87 (0.95 – 3.66)	1.84 (1.11 – 3.07) *	2.62 (1.51 – 4.56) *	1.98 (1.00 – 3.98) *	0.70 (0.27 – 1.79)	1.08 (0.64 – 1.84)

Q1 lowest quartile, Q2 two middle quartiles, Q3 highest quartile; * indicates statistical significance from the comparison (p≤0.05).

Table 4-5. Associations between cognitive performance and head impact.

Cognitive performance scale	Number (%) of falls		Total
	Head impact	No head impact	
Intact (0)	7 (46.7)	8 (53.3)	15 (100)
Borderline intact (1)	10 (58.8)	7 (41.2)	17 (100)
Mild impairment (2)	21 (52.5)	19 (47.5)	40 (100)
Moderate impairment (3)	47 (28.3)	119 (71.7)	166 (100)
Moderate-Severe Impairment (4)	19 (27.1)	51 (72.9)	70 (100)
Severe impairment (5)	42 (30.2)	97 (69.8)	139 (100)
Very severe impairment (6)	24 (32.9)	49 (67.1)	73 (100)

Chapter 5. Biomechanical and physiological determinants for hip impact during falls among older adults in long-term care

Abstract

Background: More than 90% of hip fractures in older adults are caused by falls, and the risk for hip fracture increases 30-fold by impacting the hip. An improved understanding of factors that separate falls that result in hip impact, from those that do not, may generate new opportunities for hip fracture prevention. In this study, we analyzed real-life falls captured on video in long-term care (LTC) to determine the biomechanical and physiological factors that contribute to hip impact.

Methods: Over a 7-year period (2007-2014), we captured 520 falls experienced by 160 residents who have provided consent for us to access their health records. Each video was analyzed by a 3-member team using a validated questionnaire to determine whether impact occurred to the hip or hand, the initial fall direction and landing configuration, attempts to recover balance by stepping, and use of mobility aids. We also collected information related to resident physical and cognitive function, disease diagnoses, and use of medications from the computerized Minimum Data Set system. We used Generalized Estimating Equation (GEE) models to calculate the odds ratio (OR) for hip impact associated with the various factors.

Results: Hip impact occurred in 40% of falls. Falling forward or sideways was significantly associated with higher odds of hip impact, compared to falling backward (OR = 4.2) and straight down (OR = 7.9). There was no difference in risk for hip impact between falls initially directed forward versus sideways. Sideways landing created highest odds of hip impact than landing forwards and backwards. In 32% of sideways falls, individuals rotated to land backward. This substantially reduced the odds for hip impact (0.1, 0.03-0.4). Odds of hip impact also associated with dependent ADL

performance (1.6, 1.0 – 2.4). This followed from a decreased tendency for body rotation for individuals with dependent ADL performance (0.43, 0.2-1.0).

Conclusions: Hip impact was equally likely in falls initially directed forward as sideways, due to the tendency for axial rotation of the body during descent. Risk for hip impact was lowest in falls that were initially directed straight down. In nearly one third of sideways falls, individuals rotated to land backward, and this decreased the odds of hip impact 10-fold. Individuals with impaired physical function were at higher risk of hip impact, due in part to the decreased tendency to rotate. These results may contribute to improvements in risk assessment and exercise-based strategies to reduce risk for hip fracture in older adults.

5.1. Introduction

There are approximately 28,000 annual cases of hip fracture in Canada; and more than 95% of hip fractures are caused by falls [13, 183]. In long-term care (LTC) facilities, the rates of hip fractures are as much as 10 times higher than those in the community [113]. About 25% of older adults who experience a hip fracture die within a year [5], and 50% suffer a major decline in independence such as difficulty of performing daily activities [6, 7]. Hip fractures also cause a large economic burden, accounting for $1.1 billion in direct annual health care costs in Canada [5]. Clearly, developing effective strategies to reduce the incidence of hip fractures in old adults is an essential health priority.

Previous studies have identified a range of intrinsic and situational risk factors for hip fractures, including lower limb dysfunction [13, 58], impaired balance and mobility [59, 60], high frequency of falls [72, 184, 185], low bone mineral density [67, 68], cognitive impairment [66, 71, 186, 187], and medication use [65, 71]. A similarly important, but less examined question is how risk for hip fracture depends on the mechanics of the fall itself. Of particular importance is whether impact occurs to the hip, as this increases the risk for hip fracture by 20- to 30-fold [14, 27]. Accordingly, identifying factors separating falls that result in hip impact, from those that do not, may guide hip fracture prevention efforts. Research has also shown that risk for hip fracture is increased 6-fold by falling sideways [69], presumably due to an increased probability of impact to the hip. This has led to increased emphasis on medial-lateral stability, and the prevention of sideways falls as an approach for preventing hip fractures [188, 189]. However, it is not known whether the initial fall direction governs the risk for impact to the hip, or whether specific strategies are used by older adults to avoid hip impact, including axial rotation of the torso and pelvis during the descent stage of falling [48, 49]. While young adults in laboratory experiments can exhibit this behaviour, the prevalence of these responses in real-life falls is unknown. In addition, the effectiveness of protective responses during falls in older adults may be influenced by physiological constraints, such as decreased muscle strength [111, 159], impaired attentional demands [107], and poor visual control [60, 190].

Our current understanding of fall characteristics among older adults is based on interviews or self-reports of community-dwelling older adults, and the accuracy of these data has been questioned [119, 120]. We require a better understanding of the circumstances of falls, especially for the long-term care (LTC) environment, where residents are twice as likely to fall compared to community-dwelling older adults [19]. The complex medical status of LTC residents, including the frequent co-existence of physical and cognitive impairment [20, 22], may cause the mechanisms of falls to be fundamentally different than for healthier community-dwelling seniors, necessitating a different approach to prevention.

Video capture of real-life falls provides a means of acquiring objective evidence on the mechanisms of falls in the LTC setting [126, 132, 146]. In the present study, we analyzed video footage of real-life falls experienced by older adults in LTC, addressing four specific research questions: (1) What is the prevalence of hip impact from falls in LTC? (2) What is the unadjusted association between fall mechanisms and the occurrence of hip impact? (3) What are the independent biomechanical and physiological risk factors for hip impact? (4) What are the associations between biomechanical and physiological factors leading to hip impact?

5.2. Methods

5.2.1. Video capture of falls and settings.

A sample of 160 participants with a total of 520 falls for this study was selected from analyses of falls captured on video in two LTC facilities between April 20, 2007 and June 30, 2014 (Figure 5-1). New Vista Society Care Home is an intermediate care facility with 236 beds, located in Burnaby, BC. Delta View Life Enrichment Centre is a multi-level residential care facility with 312 beds, located in Delta, BC. The New Vista facility had a network of 48 digital cameras, and the Delta View facility had 216. All cameras were located in common areas (e.g., dining rooms, lounges, activity rooms, and hallways). The videos were stored at a recording rate of 15 to 30 frames per second and a resolution of 640 × 480. This study was approved by the research ethics boards at Simon Fraser University and the Fraser Health Authority. At the time of admission to the LTC facility, each resident or proxy provided permission to the facility to acquire video footage in common areas for safety purposes. These video data were shared as secondary data with our research team. All participants in this study provided written consent for us to access their health records.

Fall videos were captured by research assistants, who communicated daily with care personnel to acquire information regarding falls occurring in common areas. The possibility of capturing a fall was based on review of fall incident reports, which records an estimate of the time and location of the fall, circumstances of the fall, use of hip protectors, and fall-related injuries. The research assistants reviewed the videos through the software on the network and extracted the fall video footages. For example, in 2012 at Delta View, 48% of falls occurred in common areas, of which 76% were captured on video. In 2012 at New Vista, 32% of falls occurred in common areas, of which 41% were captured on video.

5.2.2. Fall video analysis.

Each fall video was analyzed by three evaluators, who sought consensus of the best available answers to a Fall Video Analysis Questionnaire [145]. In the present study, we focused on questions to whether impact occurred to the hip, which was defined as an impact of the lateral aspect of the pelvis (near the greater trochanter) to the floor or other objects. We also analyzed other aspects of fall mechanisms (biomechanical variables), including the cause of imbalance, activity at time of fall, initial fall direction, landing configuration, whether impact occurred to the hand, the attempt of stepping responses, and use of mobility aids at time of fall. Tests of inter-rater and intra-rater reliability showed more than 80% agreement and a Cohen *k* value of greater than 0.67 for all these items [145]. Since falls due to slip and trip and falls during walking have been shown to have strong association with hip impact and hip fracture [14, 27, 47, 58, 191], we categorized the cause of imbalance into "slip and trip vs. all other causes" and the activity at time of fall into "walking vs. all other activities".

5.2.3. Minimum Data Set (MDS) health records.

Physiological factors were acquired through the Minimum Data Set (MDS 2.0, interRAI Corporation 1999) which is a comprehensive observational assessment of functional, medical, psychological, and cognitive status of residents in LTC [164, 165]. We focused on variables that were previously shown to associate with falls and hip fracture [66, 166], including: (1) age; (2) sex; (3) Activities of Daily Living (ADL) self-performance scale, [The ADL scale includes four items – eating, locomotion, toileting, and personal hygiene [167], with scores ranging from 0 (independent) to 6 (total dependence)]; (4) Cognitive Performance Scale (CPS), [The CPS includes five items: short-term memory, daily decision making, ability to make self understood, eating self-performance, and comatose status [168], with scores ranging from 0 (intact) to 6 (very severe impairment)]; (5) vision, [Vision ranges from 0 (adequate) to 4 (severely impaired)]; (6) diseases diagnoses, [Disease diagnoses include diabetes, Alzheimer's disease, hypertension, and stroke]; (7) use of medications, [Medications include antipsychotic, antianxiety, antidepressant, hypnotic, diuretic, and analgesics]. MDS was assessed quarterly (partial assessment) and annually (full assessment). We only selected data that were completed within 6 months prior to the fall. The average completion time was 2.1 (SD = 1.6) months prior to the fall.

5.2.4. Statistical analysis.

Due to potential correlation among repeated falls by a given resident, we used a Generalized Estimating Equation (GEE) model to examine the association between the occurrence of hip impact and biomechanical variables (fall mechanisms) and physiological variables. Participant ID and frequency of falls per participant were considered as subject variable and repeated variable in the GEE model, to account for within-participant correlation. Our outcome variable was hip impact, a dichotomous variable. Therefore, we used binary logistic link function in the GEE model.

For the physiological explanatory variables, we categorized age into lowest quartile - Q1 (<77 years), highest quartile - Q3 (>87 years), and two middle quartiles - Q2 (77-87 years). Based on the classification from previous studies [47, 66], we dichotomized the ADL scores into ‘independent’ (0-2) versus ‘dependent’ (3-6), CPS scores into ‘intact to mild impairment’ (0-2) versus ‘moderate to severe impairment’ (3-6), and vision scores into ‘adequate’ (0) versus ‘impaired’ (1-4). Sex, disease diagnoses, and use of medications were treated as dichotomous variables.

The analyses were performed using IBM SPSS 22 (IBM Corporation, Armonk, NY) and the significance level was set at $\alpha = 0.05$. We first examined the univariate associations between the occurrence of hip impact and each of the biomechanical variables and physiological. We did not include landing configuration as an explanatory variable due to the consideration that hip impact occurred during sideways landing. Therefore, sideways landing is a similar outcome as hip impact. However, we examined the influence of changes from initial fall direction to landing configuration on the occurrence of hip impact. We reported frequencies of hip impact for all levels of each explanatory variable, and odds ratios (ORs) and corresponding 95% confidence intervals (CIs) for comparisons between levels.

We then constructed multivariate models to separately examine the association (ORs and 95% CIs) of (i) biomechanical variables and (ii) physiological factors on the occurrence of hip impact. We included explanatory variables that had $p \leq 0.1$ in univariate associations, to determine independent predictors of hip impact. Age and sex were included in the multivariate analysis regardless of their p values in the univariate analyses. Finally, we examined the association between physiological factors (that was associated with hip impact in univariate or multivariate models) and fall protective mechanisms, including the change of orientation during descent, hand impact, and stepping responses.

5.3. Results

5.3.1. Participant characteristics.

Among the 160 participants included in this study, 74 (46.3%) residents had one fall captured on video, 33 (20.6%) had two, 15 (9.4%) had three, 16 (10%) had four, 5 (3.1%) had five, and 17 (10.6%) had six or more. The mean age of participants was 81.7 (SD = 9.5) years, and 62.5% were women (Table 5-1). Based on MDS data, 29.4% had Alzheimer's disease, 21.3% had diabetes, 40.0% had hypertension, 11.3% had stroke, and 2.5% had Parkinson's disease. The mean ADL performance score was 3.3 (SD = 1.5), and about 63% of participants were dependent in ADL performance. The mean cognitive performance score (CPS) was 3.8 (SD = 1.5), and about 74% of participants had moderate to severe cognitive impairment. 45% of participants used antipsychotic, 45.6% used antidepressant, and 51.2% used analgesics. These demographics and health information were similar to those of residents at New Vista and Delta View long-term care facilities (Table 5-1).

5.3.2. Prevalence of hip impact, hip fracture, and hip protectors.

Among the 520 falls analyzed, hip impact occurred in 40% of cases (n = 206), among which the hip impacted the ground in 96% of cases (n = 198), a wall in 1% (n = 2) and furniture in 2.4% (n = 5). 63% of cases (n = 130) were falls from standing height and 37% (n = 76) were falls from lower than standing height (e.g., a fall from a wheelchair). In 78% of falls where the hip impacted the ground, the flooring was vinyl or linoleum, whereas in 22% of falls it was carpet.

Based on the fall incident reports, hip protectors were documented being worn at time of fall in 73% of all falls (n = 380) in this study. Among hip impact cases, 77% (n = 160) worn hip protectors at time of fall.

Among the falls we reviewed, eight cases of hip fracture were documented. Among these, four falls occurred while individuals wore hip protectors. In two of the four cases where hip protectors were worn, the individual landed backward and impacted the buttocks instead of the hip region. The six remaining cases of hip fracture (two where hip protectors were worn and four where they were not worn) involved sideways landings and hip impact. Among sideways falls involving hip impact, hip protectors reduced the percent of falls causing hip fracture from 11% (n=4) to 2% (n=2). This is statistically significant (p=0.03), based on a Chi-Square (Fisher's exact) test.

5.3.3. Biomechanical factors and the risk of hip impact.

Among 520 falls, 12% of cases (n = 62) were due to 'slip and trip' (only two cases of slip) (Table 5-2). Falls during walking occurred in 33% (n = 171). 18% of falls (n = 96) were initially directed forward, 28% (n = 148) were sideways, 33% (n = 172) were backward, and 20% (n = 103) were straight down. 10% of falls (n = 54) involved a forward, 34% (n = 175) involved a sideways, and 56% (n = 290) involved a backward landing configurations. Hand impact occurred in 64% of cases (n = 335). Stepping responses were exhibited in 43% of falls (n = 222). 36% of falls (n = 185) involved a mobility aid.

In the univariate analyses (Table 5-2), the cause of imbalance, activity at time of fall, initial fall direction, hand impact, stepping response, and use of mobility aids were all significantly associated with hip impact. The OR for hip impact was 1.7-fold (95% CI 1.0 – 2.9) greater for falls due to slip and trip, 1.9 -fold (1.3 – 2.7) greater for falls during walking, 4.2-fold larger for falls initially directed forward or sideways than falls directed backward, and 7.9-fold larger for falls initially directed forward or sideways than falls directed straight down. There was no significant difference in odds of hip impact between falls initially directed forward compared to falls initially directed sideways. Surprisingly, the occurrence of hand impact was associated with 5.6-fold higher odds for hip impact. Stepping responses were associated with a 2.0-fold higher odds for hip impact. Use of mobility aids was associated with a 30% lower odds (0.7, 0.5 – 0.9) of hip impact.

In the multivariate analyses, initial fall direction, landing configuration, and hand impact were independently associated with hip impact. Falls initially directed forward had 3.5-fold (1.9 – 6.4) greater odds for hip impact than falls directed backward, and 5.4-fold (2.5 – 11.3) greater odds than falls directed straight down. Falls initially directed sideways were 4.1-fold (2.4 – 6.9) greater for hip impact than falls directed backward, and 6.2-fold (3.1 – 12.5) greater than falls directed straight down. Hand impact was associated with 4.1-fold (2.6 – 6.7) higher odds for hip impact compared to no hand impact. Hip impact did not associate with the cause of imbalance, activity at time of fall, use of mobility aids, and attempts to recover balance by stepping in the multivariate analysis.

5.3.4. Body rotation during descent and hip impact.

We observed a mismatch in 36% of falls between the initial fall direction and the landing configuration (Table 5-3). In 35% of falls initially directed sideways, residents rotated to land backwards, which was associated with a 10-fold reduction in the odds for hip impact (OR 0.1, 95% CI 0.03 – 0.4) (Table 5-3). Only 10% of initially sideways falls involved rotation into a forward landing configuration, although this was also associated with decreased odds for hip impact (0.01, 0.003 – 0.03). On the other hand, in 48% of falls initially directed forward, participants rotated to land sideways; this was associated with increased odds for hip impact (14.2, 4.5 – 45.4). In 18% of falls initially directed backward, participants rotated to land sideways, which was also associated with increased odds for hip impact.

5.3.5. Physiological factors and hip impact and fall protective mechanisms.

In the univariate analyses, dependent ADL performance was associated with increased odds of hip impact (OR 1.6, 95% CI 1.0 – 2.4) (Table 5-4). Moderate to severe cognitive impairment was associated with an increased odds for hip impact (1.6, 0.9 – 2.7), which reached borderline significance (p = 0.08). Age, sex, vision, diagnosis of hypertension, Alzheimer's disease, and stroke, use of medications including antipsychotic, antianxiety, antidepressant, hypnotic, diuretic, and analgesics were not associated with the occurrence of hip impact (Table 5-4). In the multivariate analysis, neither ADL performance nor cognitive performance associated significantly with the occurrence of hip impact.

Participants with independent ADL performance showed a higher frequency of body rotation from sideways to backward, compared to participants with dependent ADL performance (Table 5-5; 47% versus 30%; OR = 2.3, 95% CI: 1.0 – 5.0; p = 0.044). Furthermore, stepping responses were more frequent in participants with independent than dependent ADL performance (2.3, 1.5 – 3.5). There was no association between ADL performance and frequency of hand impact.

5.4. Discussion

Based on the analysis of real-life falls captured on video in LTC and the health records of participants captured falling, we examined whether the risk of hip impact during falling was influenced by biomechanical features of the fall (e.g., fall direction) and the clinical status of the faller (e.g., disease diagnoses, cognitive and physical status, and medications).

We found that the odds for hip impact was just as high in forward falls as in sideways falls. Given that impact to the hip increases hip fracture risk approximately 30-fold, our findings would seem to indicate that, at least for the older adults in the LTC facilities we studied, risk for hip fracture is similar in falls initially directed forward, as fall initially directed sideways. This appears to be inconsistent with previous studies (in both community and nursing home settings) reporting that falling sideways increased the risk of hip fracture by 5 - 6 folds [27, 47, 58] compared to other fall directions. Our results also disagree with laboratory studies showing that falling sideways consistently resulted in hip impact [49, 191] and falling forward was less likely to result in a hip impact [48, 191]. These discrepancies may be due to differences in the population that we sampled (older adults in LTC) and methods of data collection. In previous clinical studies, researchers have relied on the self-reported characteristics of falls, and did not separate, in their definition of "fall direction" the initial fall direction from the landing configuration. There may have been the potential for individuals to associate a sideways landing configuration with a sideways fall direction. On the other hand, laboratory studies have been restricted to examining the falling behaviour of young healthy adults, after applying sudden perturbations [48, 49] that, as our current study shows, do not represent the causes of imbalance of falls in real life for older adults.

We observed a strong tendency among participants for axial body rotation during descent, and a clear preference for "backward" as opposed to "forward" rotation. In 48% of falls initially directed forward, participants tended to rotate during descent to land sideways, which increased the odds of hip impact by 14-fold. Backward rotation likely arises as a protective response for avoiding impact to the head, since forward landing configurations are associated with the greatest risk for head impact, and backward landing configurations are associated with the lowest risk for head impact, during falls in LTC [146]. The tendency for rotation did not associate with the ADL and cognitive status of participants. Furthermore, in 35% of falls initially directed sideways, participants tended to rotate to land backward, which was associated with 10-fold decrease in the odds of hip impact. This tendency was more common in participants with independent ADL performance. Axial body rotation was observed in sideways falls experienced by young healthy adults in the laboratory setting [48], who tended to rotate forward during descent to land on both outstretched hands, and often avoided hip impact. In the current study we observed that only 10% of sideways falls involved forward rotation, which were associated with decreased odds of hip impact. An interesting hypothesis is that the tendency to rotate forward versus backward is associated with (age-related changes in) the effectiveness of upper limb protective responses for arresting the fall.

We found that hand impact did not reduce the risk of hip impact, but was instead associated with a higher odds of hip impact. This may be due to the different frequencies of hand impact in different fall directions. Hand impact occurred in 88% of forward falls and 74% of sideways falls, but only 58% of backward falls and 40% of falls straight down. Epidemiological studies have reported that hand impact is associated with decreased risk of hip fracture [47, 58]. Our current results suggest that the protective benefit of hand impact does not relate to avoidance of impact to the pelvis, but instead a reduction in the severity of the impact (and the stresses created in the proximal femur) through a sharing of impact energy. This is consistent with observations by Feldman and Robinovitch [49] in their study of sideways falls in young adults. In that study, impact to the hand(s) occurred in 95% of falls involving impact to the pelvis, and tended to occur just before impact to the pelvis. Hand impact did not reduce the frequency of hip impact, although it reduced the impact velocity of the pelvis (an outcome we were unable to examine).

Dependency in ADL performance was found to be associated with higher odds of hip impact in our univariate analysis, probably due to a reduced tendency to rotate from sideways for backward during falling. This is consistent with results from Stolee et al [66] who found that ADL impairment increased the risk of hip fracture. This was the only physiological factor, among those we examined, that associated with hip impact. This raises the question of whether avoiding hip impact is a “priority” in falling. Consistent with results from laboratory studies of falling with young adults [48, 49], our findings instead support the notion that the priority is to avoid head impact. Furthermore, in our older participants this was achieved primarily through body rotation during descent, often at the cost of generating impact to the hip.

Although hip impact occurred in 40% of the falls in our study, only eight cases (1.5% of captured falls) were documented as resulting in hip fracture. Epidemiological studies have shown that about 1-2% of falls result in hip fracture [2], while in LTC the rate is about 10 times higher [113]. Accordingly, the percentage of hip fracture cases in our study is smaller than we anticipated. One possible reason may be the relatively high use of wearable hip protectors, which were documented in 77% of falls involving hip impact. Specific types of hip protectors have been shown to reduce the risk for hip fracture if worn at the time of a fall [141], although this intervention has traditionally suffered from low user compliance limiting clinical effectiveness [192]. In this study, hip protectors were worn in four of the eight falls resulting in hip fracture. Two of the cases involved backward landing configurations, and impacted to a site posterior to the area covered by the hip protector. While we should be cautious, given our small sample of hip fractures, in drawing conclusions regarding the protective value of hip protectors, it is interesting to note that, in sideways falls involving hip impact, hip protectors reduced the percent of falls causing hip fracture from 11% to 2% (p=0.03).

Our study has several implications for risk assessment and strategies to prevent hip fractures. Balance assessment in older adults has focused mainly on lateral stability due to the association between sideways falls and hip fracture [188, 193]. For the same reasons, most laboratory fall simulations have focused on sideways perturbations [48, 49, 53]. Our results suggest that similar weight should be placed on the assessment and enhancement of anterior-posterior postural control, given that forward falls are just as likely as sideways falls to result in hip impact. While efforts should be made to enhance the effectiveness of upper limb strategies for arresting falls (e.g., through resistance training), it should be recognized that the goal here is to not prevent hip impact, but instead lessen the severity of the impact, through sharing of impact energy. Furthermore, it should be recognized that fall protective responses are governed by the priority of avoiding head impact, and for older adults in LTC, this was often achieved by rotating from forward to sideways, at the cost of experiencing hip impact. This points towards the value of hip protectors and compliant flooring to reduce the severity of the impact [182] and risk for hip fracture.

There are several limitations to this study. Our outcome variable was hip impact, a primary determinant of risk for hip fracture. We did not include hip fractures (due to a small sample of cases) in our analysis or measures of impact severity other than the occurrence of hip impact (e.g., impact velocity). We only examined falls in common areas of LTC facilities. Accordingly, our results may not apply to falls in private areas (e.g., bedrooms, bathrooms, and stairways) or to healthier older adults living in the community. Furthermore, physiological factors were acquired from MDS, which lacked detailed information on factors such as muscle strength and executive function. We did not measure the frequency and intensity of physical activities of our participants, so we were unable to determine whether risk for hip impact (or other fall mechanisms) was influenced by the physical activity level.

5.5. Conclusion

This study provides the first evidence of how biomechanical and physiological factors influence the risk of hip impact during falls in older adults in LTC. Hip impact was equally likely in falls initially directed forward as sideways, due to the common tendency for axial rotation of the body during descent. Rotation from sideways to backward decreased the odds of hip impact 10-fold. Individuals with impaired physical function were at higher risk of hip impact, due in part to their decreased tendency to rotate. These results may contribute to improvements in risk assessment and exercise-based strategies to reduce the risk for fall-related hip fractures in older adults.

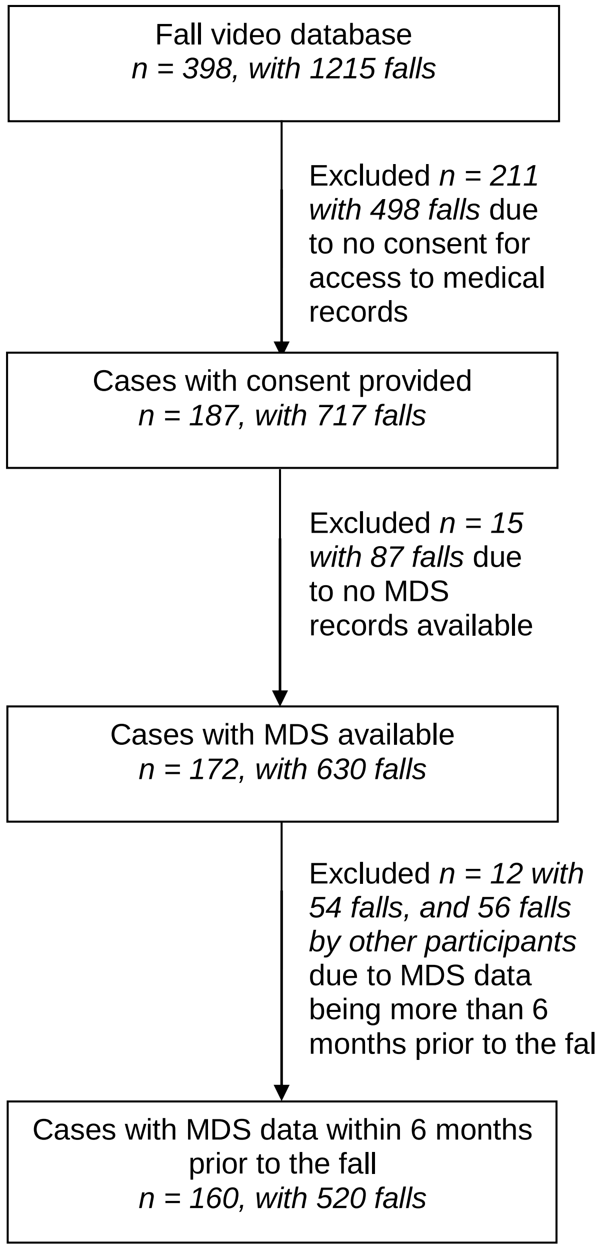

Figure 5-1. Flow chart of sample selection (participants and falls) in this study.

Table 5-1. Characteristics of participants in this study and the current residents at New Vista and Delta View long-term care facilities.

	New Vista residents (n=235)	Delta View residents (n=211)	Participants in this study (n=160)
Demographics and health condition			
Age (mean, (SD))	83.1 (9.6)	81.7 (11)	81.7 (9.5)
Female (n, (%))	164 (69.7)	132 (62.5)	100 (62.5)
Dependent ADL performance (n, (%))	163 (69.4)	146 (69.3)	101 (63.1)
Moderate to severe cognitive impairment (n, (%))	187 (79.6)	175 (83)	119 (74.4)
Impaired vision (n, (%))	78 (33.2)	81 (38.4)	63 (39.4)
Disease Diagnoses (n, (%))			
Alzheimer's Disease	45 (19.1)	59 (28.0)	47 (29.4)
Diabetes	46 (19.6)	55 (26.1)	34 (21.3)
Cardiac arrhythmia	7 (3.0)	6 (2.8)	8 (5.0)
Hypertension	117 (49.8)	107 (50.7)	64 (40)
Hypotension	1 (0.4)	2 (0.9)	2 (1.2)
Stroke	35 (15.0)	43 (20.4)	18 (11.3)
Parkinson's Disease	10 (4.3)	8 (3.8)	4 (2.5)
COPD	34 (14.5)	26 (12.3)	19 (11.9)
Use of Medications (n, (%))			
Antipsychotic	88 (37.4)	75 (35.5)	72 (45)
Antianxiety	51 (21.7)	36 (17.1)	30 (18.8)
Antidepressant	110 (46.8)	87 (41.2)	73 (45.6)
Hypnotic	58 (24.7)	33 (15.6)	23 (14.4)
Diuretic	69 (29.4)	60 (28.4)	36 (22.5)
Analgesics	113 (48.1)	109 (51.7)	82 (51.2)

SD, standard deviation; n, absolute number of residents.

Table 5-2. Univariate and Multivariate analysis of biomechanical factors associated with risk for hip impact.

Variables being compared	Number (%) of falls		Univariate analysis		Multivariate analysis	
	Hip impact	No hip impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
§ Cause of imbalance						
Slip and trip vs.	31 (51)	30 (49)	1.7 (1.0 – 2.9)	0.053	0.8 (0.4 – 1.6)	0.499
Other causes (reference)	175 (38)	282 (62)				
§ Activity at time of fall						
Walking vs.	84 (49)	86 (51)	1.9 (1.3 – 2.7)	**0.001**	0.9 (0.5 – 1.5)	0.577
Other activities (reference)	122 (35)	227 (65)				
§ Initial fall direction						
Forward vs.	57 (59)	39 (41)	1.0 (0.6 – 1.7)	1.000	0.9 (0.5 – 1.5)	0.617
Sideways (reference)	88 (60)	60 (40)				
Forward vs.	57 (59)	39 (41)	4.2 (2.4 – 7.1)	**< 0.001**	3.5 (1.9 – 6.4)	**< 0.001**1
Backward (reference)	45 (26)	127 (74)				
Forward vs.	57 (59)	39 (41)	7.9 (4.1 – 15.6)	**< 0.001**	5.4 (2.5 – 11.3)	**< 0.001**
Straight down (reference)	16 (15)	87 (85)				
Sideways vs.	88 (60)	60 (40)	4.2 (2.6 – 6.7)	**< 0.001**	4.1 (2.4 – 6.9)	**< 0.001**
Backward (reference)	45 (26)	127 (74)				
Sideways vs.	88 (60)	60 (40)	7.9 (4.3 – 14.9)	**< 0.001**	6.2 (3.1 – 12.5)	**< 0.001**
Straight down (reference)	16 (15)	87 (85)				
Backward vs.	45 (26)	127 (74)	1.9 (1.0 – 3.6)	**0.044**	1.5 (0.8 – 3.0)	0.227
Straight down (reference)	16 (15)	87 (85)				

Variables being compared	Number (%) of falls		Univariate analysis		Multivariate analysis	
	Hip impact	No hip impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
§ Use of mobility aids vs.	63 (34)	122 (66)	0.7 (0.5 – 0.9)	**0.043**	0.9 (0.6 – 1.4)	0.619
None (reference)	143 (43)	191 (57)				
§ Hand impact vs.	176 (53)	159 (47)	5.6 (3.6 – 8.8)	**< 0.001**	4.1 (2.6 – 6.7)	**< 0.001**
No hand impact (reference)	30 (16)	153 (84)				
§ Stepping response vs.	109 (49)	113 (51)	2.0 (1.4 – 3.3)	**< 0.001**	1.1 (0.6 – 1.8)	0.801
No stepping (reference)	97 (33)	200 (67)				

CI, confidence interval; § variables were included in the multivariate analysis.

Table 5-3. Change of fall direction from the initiation of fall to landing, with corresponding number of falls and probabilities for hip impact.

Change of Fall Direction		Number (%) of falls			Odds Ratio (95% CI)	P-Value
Initial Fall Direction	**Landing Configuration**	**Total**	**Hip Impact**	**No Hip Impact**		
Forward	***n* = 96**					
	Forward	37 (39)	14 (38)	23 (62)	Reference	
	Backward	13 (13)	2 (15)	11 (85)	0.3 (0.06 – 1.7)	0.181
	Sideways	46 (48)	41 (89)	5 (11)	14.2 (4.5 – 45.4)	**< 0.001**
Backward	***n* = 172**					
	Forward	0 (0)	0 (0)	0 (0)	‡	
	Backward	141 (82)	17 (12)	124 (88)	Reference	
	Sideways	31 (18)	28 (90)	3 (10)	68.1 (18.6 – 249)	**< 0.001**
Sideways	***n* = 148**					
	Forward	15 (10)	8 (53)	7 (47)	0.01 (0.003 – 0.03)	**< 0.001**
	Backward	51 (35)	5 (10)	46 (90)	0.1 (0.03 – 0.4)	**0.001**
	Sideways	82 (55)	75 (92)	7 (8)	Reference	
Straight down	***n* = 103**					
	Forward	2 (2)	0 (0)	2 (100)	–§	
	Backward	85 (82)	5 (6)	80 (94)	–§	
	Sideways	16 (16)	11 (69)	5 (31)	–§	

Note: ‡We were unable to calculate an OR for backward to forward (owing to 0 cases). §We were unable to calculate ORs for falls initially directed straight down, because a straight down landing configuration was not included as an option in our questionnaire.

Table 5-4. Univariate and Multivariate analysis of physiological factors associated with risk for hip impact.

Variables being compared	Number (%) of falls		Univeriate analysis		Multivariate analysis	
	Hip impact	No hip impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
§ Age						
Q1(<77) vs.	52 (39)	80 (61)	0.9 (0.6 – 1.4)	0.552	0.9 (0.6 – 1.4)	0.607
Q2 (77-87) vs.	99 (42)	138 (58)	0.8 (0.6 – 1.3)	0.334	0.8 (0.5 – 1.3)	0.374
Q3 (>87) (reference)	55 (37)	95 (63)				
§ Female vs.	114 (39)	180 (61)	0.9 (0.6 – 1.3)	0.446	0.9 (0.6 – 1.3)	0.514
Male (reference)	92 (41)	133 (59)				
§ ADL performance						
Dependent vs.	167 (42)	230 (58)	1.6 (1.0 – 2.4)	**0.044**	1.4 (0.9 – 2.3)	0.157
Independent (reference)	39 (32)	83 (68)				
§ Cognitive impairment						
Moderate to severe vs.	184 (41)	263 (59)	1.6 (0.9 – 2.7)	0.082	1.3 (0.7 – 2.4)	0.398
Intact to mild (reference)	22 (31)	50 (69)				
Impaired vision vs.	86 (40)	131 (60)	1.0 (0.7 – 1.4)	0.914		
Adequate vision (reference)	120 (40)	182 (60)				
Hypertension vs.	72 (38)	116 (62)	0.9 (0.6 – 1.3)	0.562		
No (reference)	134 (40)	197 (60)				
Alzheimer's disease vs.	97 (39)	149 (61)	1.0 (0.7 – 1.4)	0.951		
No (reference)	109 (40)	164 (60)				

Variables being compared	Number (%) of falls		Univeriate analysis		Multivariate analysis	
	Hip impact	No hip impact	Odds Ratio (95% CI)	P-Value	Odds Ratio (95% CI)	P-Value
Stroke vs.	18 (35)	34 (65)	0.7 (0.4 – 1.4)	0.348		
No (reference)	188 (40)	279 (60)				
Use of medication						
Antipsychotic vs.	94 (38)	154 (62)	0.9 (0.6 – 1.3)	0.481		
No (reference)	112 (41)	159 (59)				
Antianxiety vs.	36 (35)	67 (65)	0.8 (0.5 – 1.2)	0.235		
No (reference)	170 (41)	246 (59)				
Antidepressant vs.	102 (39)	162 (61)	0.9 (0.7 – 1.3)	0.730		
No (reference)	104 (41)	151 (59)				
Hypnotic vs.	25 (36)	45 (64)	0.8 (0.5 – 1.4)	0.412		
No (reference)	181 (40)	268 (60)				
Diuretic vs.	44 (35)	82 (65)	0.7 (0.5 – 1.1)	0.122		
No (reference)	162 (41)	231 (59)				
Analgesics vs.	106 (42)	145 (58)	1.2 (0.8 – 1.7)	0.322		
No (reference)	100 (37)	168 (63)				

Q1 lowest quartile, Q2 two middle quartiles, Q3 highest quartile; CI, confidence interval; § variables were included in the multivariate analysis.

Table 5-5. Effect of ADL on the change of orientation from falling to landing, hand impact and stepping response.

		Number (%) of falls		Odds ratio (95% CI)	P - Value
Change of Fall Direction		**ADL performance**			
Initial Fall Direction	**Landing Configuration**	**Independent**	**Dependent**		
Forward	**Forward**	15 (48)	22 (34)	Reference	
	Backward	4 (13)	9 (14)	0.8 (0.2 – 3.2)	0.733
	Sideways	12 (39)	34 (52)	0.5 (0.2 – 1.4)	0.187
Backward	**Forward**	0 (0)	0 (0)	‡	
	Backward	30 (79)	111 (83)	Reference	
	Sideways	8 (21)	23 (17)	1.3 (0.5 – 3.1)	0.597
Sideways	**Forward**	4 (11)	11 (10)	1.6 (0.4 – 5.6)	0.492
	Backward	18 (47)	33 (30)	2.3 (1.0 – 5.0)	**0.044**
	Sideways	16 (42)	66 (60)	Reference	
Straight down	**Forward**	1 (7)	1 (1)	–§	
	Backward	12 (80)	73 (83)	–§	
	Sideways	2 (13)	14 (16)	–§	
Hand impact	**Yes**	86 (71)	249 (63)	1.4 (0.9 – 2.2)	0.138
	No	36 (29)	148 (37)	Reference	
Stepping response	**Yes**	71 (58)	151 (38)	2.3 (1.5 – 3.5)	**< 0.001**
	No	51 (42)	246 (62)	Reference	

‡We were unable to calculate an OR for backward to forward (owing to 0 cases). §We were unable to calculate ORs for falls initially directed straight down, because a straight down landing configuration was not included as an option in our questionnaire.

Chapter 6. Thesis synthesis and future directions

While researchers have studied the cause and prevention of falls in older adults for at least 40 years, there has been a lack of objective evidence of the biomechanical characteristics of falls, to link with the clinical context. This PhD research addresses this gap by describing evidence from video capture of "how" and "why" falls occur in older adults residing in LTC. In this section, I summarize the main findings of my research, and discuss how they contribute to our knowledge base on falls in older adults. I also consider the implications of my results for practice and policy in fall prevention, and identify key areas for future research.

As described in chapter 2, two early milestones that established the basis for my thesis were (a) the development of techniques to collect video footage of real-life falls in older adults in long-term care, and (b) the development and validation of a structured questionnaire, completed by a team of three experts, for categorizing the characteristics of falls from video footage of the events.

Working closely with staff at the two participating long-term care facilities, we developed a method for reviewing incident reports and collecting footage of falls from networks of digital video cameras in common areas of the facilities (dining rooms, lounges, and hallways). While many cameras were pre-existing, some were added by the research team. This method allowed us to collect, for the first time, a large database of real-life falls in older adults captured on video. A limitation of our approach was that no falls were collected in bedrooms or bathrooms (where about 55% of all falls occurred), which, due to environmental or situational factors, may be different in important ways from falls in common areas.

My 24-item fall video analysis questionnaire (FVAQ) focuses on the initiation, descent, and impact stages of the fall, and provides a validated approach for collecting categorical data on the characteristics of falls captured on video. I developed the FVAQ based on synthesis of the falling literature, and an iterative process to ensure the responses to each question captured the most common behaviours observed in my fall videos. I focused on the cause of imbalance and activity at the time of the fall, which are important for fall risk assessment, balance training protocols, laboratory simulation of falls, and identification of environmental hazards. I included balance recovery by stepping, and upper limb protective responses as a measure of the integrity of established protective responses. Furthermore, I focused on impact to the pelvis, head and hand – the most common sites of serious injury from falls in older adults.

I found good reliability (with an agreement of more than 80% and a kappa of over 0.6) for 17 of 24 items in the questionnaire. The FVAQ reliably captured several key variables that formed the basis for my subsequent studies. These included the cause of imbalance, activity at the time of falling, direction of the fall, execution of balance recovery responses, landing configuration, and impact locations. Questions with low reliability included footwear worn at the time of falling, which should be addressable through improvements in the quality of the video.

A limitation of the FVAQ is that it focuses on a time interval of video footage starting 2-3 minutes before the onset of imbalance, and ending 1-2 minutes after landing. Analysis of movements and behaviours (and staff interactions) over a longer period leading up to the fall may provide additional insight on causative factors [153]. Likewise, examination of the post-fall stage, involving rising from the fall (which in the vast majority of cases in LTC required the assistance from care providers) is an important topic of future work. Published in BMC Geriatrics, the FVAQ is freely available for download and use by other researchers, who may wish to develop analysis packages that build on the core template.

Clinical research on falls in the long-term care environment often relies on fall incident reports, which are completed by nursing staff and often include brief descriptions of the cause and circumstances of the fall. However, many falls are unwitnessed, and there are no direct measures of the accuracy of the information typically gathered from fall incident reports [114, 119]. In chapter 3, I compared fall characteristics documented on incident reports to those observed from video analysis of the same fall. My results highlight the need, and suggest possible approaches to improve the accuracy and clinical utility of fall incident reports in the long-term care setting. I found 45.5% agreement on the cause of imbalance (Kappa = 0.25), 45.1% agreement on activity at time of falling (Kappa = 0.22), and 79.5% agreement on use of mobility aids (Kappa = 0.59). Of 49 reported slips, only two were observed on video as slips. On the other hand, falls due to loss of support with an external object (e.g., unlocked wheelchair), and hit/bump (often caused by aggression) were under-reported. Falls during rising were over-reported, while falls during sitting down were under-reported. Use of a wheelchair or walker was over-reported. These results provide clues for staff to improve the accuracy of fall incident reports. They also support the need for the development of autonomous, unobtrusive technologies (e.g., infrared video cameras, wearable sensors) for detecting falls, and obtaining reliable data on fall characteristics. This is currently an intense of research among biomedical engineers [154, 155], although no study to date has examined the clinical utility of such systems in the management and prevention of falls.

In chapter 4, I focused on a project relevant to prevention of one of the most serious consequences from falls – brain injury. Over the past decade, there has been a 3-fold increase in the age-adjusted rate of traumatic brain injury from falls in older adults [10, 173]. Based on analysis of our video library, I examined the prevalence and risk factors for head impact during falls among older adults in LTC. I found that nearly one-third of falls in this population involve impact to the head. The odds for head impact were over 2-fold higher among women when compared to men. This was due to the tendency for women to fall during walking (as opposed to other activities), which increased risk for head impact. I also found that risk for head impact was increased among individuals with impaired vision – a risk factor amenable to intervention. This complements previous evidence that impaired vision increases risk for hip fracture in the event of a fall [60].

This study also revealed some important surprising findings. First, the problem of head impact was not restricted to those who more impaired in cognitive and physical performance. In fact, I observed the opposite trend. Individuals with higher cognitive function (based on the MDS CPS scale) and higher independence in ability to perform daily activities (based on the MDS ADL scale) were more likely to experience head impact in a fall, than those who were more impaired in cognition and mobility. This again reflected that the less impaired group was more likely to fall during walking, and fall in the forward direction.

Second, the population of older adults that we examined appear to have lost the ability to effective arrest the fall with the outstretched arms. Despite the observation that hand impact was very common (observed in 65% of all falls, and 88% of forward falls), the occurrence of impact to one or both hand(s) did not associate with risk for head impact. Young adults commonly use upper limb fall arrest strategies to avoid head impact during falls [48, 49], but this is a strength demanding task [111, 159]. Further research is required to understand the relative roles of hand placement, muscle strength (and arm collapse), and neural activation in determining the ability of older adults to successfully avoid head impact through upper limb fall arrest strategies. This should help to inform the design of exercise-based approaches to enhance upper limb fall arrest strategies.

Third, we observed an alternative strategy for avoiding head impact during falls in older adults, of rotating during descent to change the fall direction from forward to sideways or backward. This was observed in 61% of all forward falls, and caused a 2.7-fold reduction in risk for head impact. This observation is also significant in indicating that falls cannot be considered to have a single direction, since the direction often changes markedly between the interval from the onset of the fall and landing. An interesting hypothesis (for future research) is that the tendency to rotate associates with the integrity of upper limb fall arrest strategies. A similar strategy of rotation during descent (and avoidance of upper limb fall arrest) is practiced in the Ukemi falling technique in Judo, which may provide to be surprisingly applicable to older adults [112].

Finally, although 47% of all documented injuries in fall incident reports were to the head, no concussions were noted. This probably reflects (given the severity of the impacts we observed and rigidity of the vinyl flooring in the facilities we studied) the difficulties of separating the neural consequences of the falls from baseline dementia in residents of LTC [180]. Improved approaches are required to identify brain injuries in this population.

Impact to the hip causes a 30-fold increase in the risk for hip fracture during falls in older adults [14], and sideways falls cause a 6-fold increase [47]. In chapter 5, I analyzed our video database to determine how biomechanical and physiological factors influence the risk for hip impact. Surprisingly, I found that the risk for hip impact was similar during falls initially directed forward as falls initially directed sideways. Thus, the assessment and targeting of postural stability about the anterior-posterior axis, as well as medial-lateral axis, is important in developing hip fracture prevention strategies. The reason why forward falls were just as likely as sideways falls to cause hip impact appeared to relate to (a) the tendency (discussed above in terms of its relevance to head impact) for individuals to rotate during descent to convert forward falls to sideways landing configurations; and (b) the tendency for individuals to rotate to convert sideways falls to backward falls (observed in 35% of sideways falls). The tendency to rotate was less common among individuals with impaired physical function.

My results suggest additional important directions for future research. I focused on whether impact occurred to a given body part, but I did not measure impact velocities, or other measures of impact severity. Also, my study lacked sufficient numbers of injuries to analyze the factors leading to severe brain injury, or hip fracture. The quality of the video we analyzed was less than what could be provided with state-of-the-art technology (e.g., Microsoft Kinect or cameras with higher capture rates and resolutions). Due to privacy considerations, I did not record or analyze falls in bedrooms and bathrooms, which might be studied with less invasive approaches (e.g., infrared cameras or sensors). Video capture also provides a means to monitor (in real-time) the effect of interventions (e.g., environmental modifications or exercise programs), and neither was a focus on my research. I focused on the analysis of falls, and not "near-fall" or successful performance of daily activities (e.g., walking, transferring from chairs or wheelchairs, and standing). Adding these activities into future analysis, and linking them to the clinical context (disease diagnoses, physical and cognitive function, and medications) may facilitate improved understanding and targeting of “what went wrong.”

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Appendix:

Fall Video Analysis Questionnaire (FVAQ) – Short Version

Video details.

Record the following details on the video.

(a) Video identification code: ______________
(b) Location of fall (facility): ______________
(c) Date of fall: ______________
(d) Date of analysis: ______________
(e) Team members: ______________
(f) Team leader: ______________

Question 1. Cause of fall.

Describe the primary cause of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Slip
ii. Trip/stumble
iii. Hit/bump
iv. Fell asleep/legs collapsed/loss of consciousness
v. Incorrect transfer/shift of body weight
vi. Loss of support with external object

Probability: _________

Question 2. Activity at time of fall.

Describe what the person was doing when he or she lost balance and fell. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Lost balance while transferring from standing
ii. Lost balance while transferring from a sitting or lying position
iii. Lost balance while seated/wheeling in wheelchair
iv. Lost balance while walking
v. Lost balance while standing

Probability: _________

Question 3. Mobility aids.

Describe whether a mobility aid was present at the time of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Cane in use
ii. Wheelchair in use
iii. Walker in use
iv. Crutch in use
v. Cane visible (suspected to belong to the individual) but not being used
vi. Wheelchair visible (suspected to belong to the individual) but not being used
vii. Walker visible (suspected to belong to the individual) but not being used
viii. Crutch visible (suspected to belong to the individual) but not being used
ix. None visible belonging to the individual

Probability: __________

Question 4. Initial fall direction.

Describe the initial direction of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Primarily forward
ii. Primarily backward
iii. Primarily sideways
iv. Straight down

Probability: __________

Question 5. Landing configuration.

Describe the configuration of the body at landing from the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Primarily forward
ii. Primarily backward
iii. Primarily sideways

Probability: __________

Question 6. Floor material.

Describe the type of floor surface the individual landed on. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Carpet
ii. Concrete
iii. Linoleum or vinyl tile
iv. Padded mat/ compliant flooring
v. Did not land on floor

Probability: __________

Question 7. Perceived site of greatest energy absorption.

Identify the body part that absorbed the majority of energy/contact force during the impact stage of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Head
ii. Pelvis/torso/buttocks
iii. Upper limb
iv. Lower limb

Probability: __________

Question 8. Perceived injury risk/ impact severity.

Identify the body part that appeared to be the greatest risk for injury during the impact stage of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Head
ii. Pelvis/torso/buttocks
iii. Upper limb
iv. Lower limb

Probability: __________

Question 9. Head impact.

Did impact occur to the head during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 10. Pelvis impact.

Did impact occur to the pelvis during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 11. Torso impact.

Did impact occur to the torso during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 12. Hand/ wrist impact.

Did impact occur to the hand(s)/wrist(s) during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 13. Elbow/ forearm impact.

Did impact occur to the elbow(s)/ forearm(s) during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 14. Knee impact.

Did impact occur to the knee(s) during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 15. Shoulder impact.

Did impact occur to the shoulder(s) during the fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 16. Stepping responses.

Did the individual attempt to recover balance by taking one or more steps? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 17. Held objects.

Was the individual carrying or grasping an object at time of fall? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 18. Reach-to-grasp responses.

Did the individual attempt to recover balance by reaching to grasp an external object? Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes
ii. No

Probability: __________

Question 19. Height of fall.

Describe the height of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Standing height
ii. Lower than standing height
iii. Greater than standing height

Probability: __________

Question 20. Footwear.

Describe the footwear worn by the resident at the time of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Shoes
ii. Socks
iii. Slippers/ sandals
iv. Bare feet

Probability: __________

Question 21. Floor conditions (Wet/Dry).

Describe whether the floor was wet or dry at the site of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Wet
ii. Dry

Probability: __________

Question 22. Floor conditions (Transition).

Describe whether there were transitions in the colour, pattern, texture, or height of the floor at the site of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Yes, there were transitions in the colour, pattern, texture, or height of the floor at the site of the fall
ii. No, there were no apparent transitions in the colour, pattern, texture, or height of the floor at the site of the fall

Probability: __________

Question 23. Lighting.

Describe the general lighting conditions at the site of the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Well lit (bright light)
ii. Poorly lit (dark or dim lighting)

Probability: __________

Question 24. Contribution of clutter.

Describe the apparent contribution of clutter (surrounding objects, furniture, or people) in causing the fall. Select the best answer among those listed. Estimate the percent probability (1-100%) of your answer being correct at the bottom.

i. Clutter contributed to the cause of the fall
ii. Clutter had little contribution to the cause of the fall

Probability: __________