Protective Responses during a Sideways Fall: Effects of Secondary Tasks

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Falls and hip fractures are a major public health problem among the elderly. In addition to bone strength, sideways falls and direct hip impact are important determinants for hip fracture. However, few falls actually cause serious injury in both young and older adults. Therefore, understanding how individuals facilitate a safe landing during a fall will help guide appropriate exercise-based training programs. The primary purpose of this thesis was to investigate the effects of secondary tasks on movement strategies during a sideways fall.

To address this aim, I used a tether and electromagnet to suddenly release subjects from a sideways leaning position, causing them to fall onto a gymnasium mat. I instructed subjects to "fall and protect yourself, as if you were landing on a hard surface". I acquired trials in four conditions, presented in a pseudo-random order: falling while holding a box, falling while holding an empty mug, falling while reciting spoken text, and falling with no secondary task. In most trials, regardless of condition, impact occurred to the lateral aspect of the pelvis (no secondary task = 87%, box = 82%, cognitive = 90%, mug = 79%). While the frequency of impact to both hands decreased when carrying an object (box=67%, mug=50% compared to cognitive=90% and no secondary task=85%), 40% of trials in the mug condition involved one hand contacting the ground, indicating hand impact was still common. It appears when protective movements such as impact to the knees and hands did occur, they were not used to avoid direct hip impact. Instead, they were used to help break the fall, and to avoid head impact, which was not seen in this experiment. The results from this study indicate that secondary tasks have minimal effects on fall responses and that the rare occurrence of hip fractures in the young is due to some combination of bone strength and effective use of body segments to break the fall.

In a second study, I examined how a cognitive task affected the ability of young women to rotate forward (FR) or backward (BR) during a sideways fall. Subjects were released from a sideways leaning position and were provided with a visual cue upon tether release instructing them on the desired direction of rotation. The site of impact on the pelvis (as reflected by the hip proximity angle) was closer to the lateral aspect of the hip in cognitive trials than in control trials ($43 \pm 18^\circ$ versus $51 \pm 19^\circ$ in FR and $59 \pm 18^\circ$ versus $68 \pm 18^\circ$ in BR) ($p=0.0006$). This was due to a longer delay in the initiation of rotation in cognitive trials (293 ± 60 ms versus 232 ± 71 ms in FR and 278 ± 87 ms versus 239 ± 60 ms), as opposed to a change in mean angular velocity. Pelvis impact velocity was similar in the two conditions (2.6 ± 0.3 m/s compared to 2.7 ± 0.3 m/s in FR trials and 2.8 ± 0.2 m/s compared to 2.9 ± 0.2 m/s in BR trials) ($p=0.0514$). The results from this study indicate that involvement in a secondary task can impair safe landing responses. Secondary attentional tasks cause a delay in the initiation of fall protective responses, which alters landing configuration. However, the motor programme that governs falling, remaining consistent across condition is robust to changes in task execution at the onset of the fall.

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Chapter 1 General Introduction and Literature Review

1.1 General Introduction

Falls occur among people of varying ages, but they are a major health problem for the elderly and are the leading cause for death, disability and injury in this population (Nevitt et al., 1989; Tinetti and Speechley, 1989; Hayes et al., 1996).

However, only 1-2% of falls in the elderly result in hip fracture (Gryfe et al., 1977; Nevitt, et al., 1989; Tinetti et al., 1988) and fewer than 10% cause serious injury. This suggests that certain common protective responses are used to land safely during a fall (Cummings and Nevitt, 1989; Robinovitch et al., 2003). Improved understanding of the nature and factors which influence the efficacy of these responses can help guide appropriate exercise-based training programs.

The experiments described in this thesis provide important new insight into strategies young individuals utilize to protect themselves during a fall, and how secondary tasks affect the dynamics of a fall.

1.2 Literature Review

1.2.1 Incidence of Falls

There are three general groups of people who are at a high risk for fall-related injuries: older adults over age 65, children between the ages of 6-10, and individuals who work at various heights (Robinovitch, 1999). It is among the elderly however that falls are a major health problem, as one third of people 65 years or older fall each year (Speechley and Tinetti, 1991). In Canada, falls account for estimated medical costs of about $1 billion (Papadimitropoulos et al., 1997). As the population continues to age, fall-induced injuries and deaths are likely to increase (Rubenstein et al., 1994). While the prevention of falls is an essential goal for reducing the incidence of fall-related injuries, it is also important to understand how individuals avoid injury during a fall. This research improves our knowledge of safe landing strategies during falling, which has implications for understanding and preventing injuries among both young and older adults.

1.2.2 Fall Risk Factors

It is well established that several causes of instability can result in a fall. Falls are often caused by slips, trips, or a sudden loss of balance during daily movements such as walking, turning, bending or rising (Nevitt and Cummings, 1993). The risk for falls among older adults is dependent upon various extrinsic (e.g., environmental) and intrinsic (e.g., neuromuscular) factors. Fall risk increases with certain environmental factors, such as poor lighting (Weir and Culmer, 2004). Furthermore, falls are precipitated by many disease- and age-related declines in neurological and musculoskeletal function such as: dementia, Parkinson's, use of psycho-active medications, impairments to vision, hearing, reaction time and lower muscular strength (Wolfson et al., 1985; Cummings and Nevitt, 1989; Tinetti, 1994; Kannus et al., 1999; Woollacott and Shumway-Cook, 2002). While these factors influence the risk for falls in the event of a fall, I am unaware of how they affect the dynamics of an actual fall. The results from this thesis stress the importance of response time and allocation of attention on impact severity during a sideways fall.

1.2.3 Fall-related Injuries

Among the elderly, falls are a major cause of injury and death, often leading to a loss of mobility, independence and a decline in overall quality of life (Cummings and Nevitt, 1994; Schwartz et al., 1998; Kannus et al., 2005). Falls from adults over 65 comprise over 80% of injury related admissions to the hospital and are among the leading causes of brain injuries (Kannus et al., 1999; Pickett et al., 2001; Weir and Culmer, 2004). Injuries from a falls include: hip fractures, wrist fractures, vertebral fractures, head injuries, fractures of the proximal humerus, joint dislocations, severe lacerations and soft tissues injuries (Tinetti et al., 1988; Nevitt et al., 1989; Nevitt et al., 1993; Cooper et al., 1992).

The most serious type of injury in terms of frequency, medical costs and morbidity is hip fractures. In the elderly, falls account for over 90% of hip fractures (Grisso et al., 1991), with about 23,000 cases of hip fracture occurring in Canada annually and over 250,000 occurring in the United States (Papadimitropoulos et al., 1997). Furthermore, the incidence of hip fractures is two to three times greater in women than men (Zuckerman et al., 1996). The occurrence of hip fractures increases exponentially with age and is expected to increase 4-fold by 2041 if successful interventions are not put in place (Jaglal et al., 1996; Papadimitropoulos et al., 1997). In addition wrist fractures are also common among both young and older adults (Palvanen et al., 2000).

1.2.4 Biomechanics of Falls

A fall can be considered to have four stages (Hayes et al., 1996): (1) an initiation stage, involving a loss of balance resulting in instability; (2) a descent stage, involving both attempted and executed movements in preparation for landing; (3) an impact stage, which involves contact between the body and the ground; and (4) a post impact stage, where the subject comes to a rest. The majority of research on falls has focused almost entirely on fall initiation and balance recovery rather than the descent stages of a fall (Do et al., 1982; Chen et al., 1994; Luchies et al., 1994; Grabiner et al., 1993; Romick-Allen and Schultz, 1988). By contrast, research on fall mechanics is scarce, due in part to the difficulty ensuring participants remain safe throughout testing sessions.

1.2.4.1 Kinematics of a Fall

1.2.4.1.1. Fall Severity

Bone mineral density is an important contributor to hip fractures, as studies have found that the risk of hip fracture increases with decreasing bone mineral density of the proximal femur (Cummings and Nevitt, 1989; Hayes et al., 1996). However, factors related to the dynamics of a fall, including the direction of the fall and the impact location also play an important role in the etiology of hip fractures (Speechley and Tinetti, 1991; Hayes et al., 1993; Nevitt and Cummings, 1993; Kannus et al., 1996; van den Kroonenberg et al., 1996; Schwartz et al., 1998). Studies examining the epidemiology of falls have discovered that falling sideways increases the risk for fracture by 6-fold (Nevitt and Cummings, 1993; Greenspan et al., 1994). Individuals who landed on or near the hip were 30 times more likely to suffer hip fractures (Nevitt and Cummings, 1993, Greenspan et al., 1994). Those who used the hand or knee to break the fall were 3-fold less likely to fracture. These results suggest that fracture risk during falling depends on the ability to utilize protective movements aimed at landing safely. However, very little is known about the nature and factors that affect these responses.

The study by van den Kroonenberg et al., (1996) was the first to examine falls from standing height using human subjects. They measured hip impact velocity, which along with the effective mass and stiffness of the body influences the contact forces at the hip. They found that muscle-relaxed falls resulted in a reduction in hip impact velocities and that most subjects were unable to break their falls with the outstretched hands. However, a major limitation for their study was that the falls were self-initiated, while falls in real life are usually unexpected.

Hsiao and Robinovitch (1998) examined the role of protective responses during falls from standing height. They found that, in young people during unexpected slips, impact to the outstretched hand occurred in over 90% of all falls while impact to the lateral aspect of the hip was avoided.

In a more recent study Robinovitch et al. (2003) investigated the ability of young individuals to avoid hip impact by rotating either forward or backward during a sideways fall (Robinovitch et al., 2003). They found that subjects were equally successful in avoiding hip impact by rotating forward or backward. However, a limitation to this study was that the subjects were informed about the desired falling technique before they fell and were therefore able to plan their descent. The second study (Chapter 3) in this thesis improves on this methodology cueing the subject about the desired direction of rotation at the instant of the perturbation, thus eliminating the ability of subjects to pre-plan their responses.

1.2.5 Dual-Task Research and the Role of Attention

1.2.5.1 The Role of Attention in Balance Maintenance

Research suggests that the performance of attention demanding tasks can increase the risk for falls in older adults (Lajoie et al, 1993; Tideiksaar, 1996; Sparrow et al., 2002). Attention can be defined as the limited capacity for individuals to process information (Woollacott and Shumway-Cook, 2002). So, if two tasks are performed concurrently, performance on one or both may deteriorate if they require more than the available attentional resources (Shumway-Cook and Woollacott, 2000; Woollacott and Shumway-Cook, 2002). Dual task paradigms involve performing both a postural task and a secondary task together, and the extent to which both tasks share attentional resources is determined by a decline in performance of either task (Kerr et al., 1985). In the first experiment (Chapter 2), dual-task methods were used to explore how fall protective responses are modified while performing various secondary tasks. The second experiment (Chapter 3) in this thesis uses the dual-task paradigm to investigate the role of attention on the ability to employ specific protective responses during a fall.

Over the years, posture and balance have been widely examined using a dual-task method, with several studies indicating that the maintenance of balance competes with other tasks for limited cognitive resources (Kerr et al., 1985; Guerts 1988; Maki and McIlroy, 1996; Brown et al., 1999; Shumway-Cook and Woollacott, 2000; Dault et al., 2001; Yardley et al., 2001; Müller et al., 2004). Kerr et al. (1985) first demonstrated that postural control was attentionally demanding by finding interference between a cognitive task and a postural task. Furthermore, several researchers have demonstrated that the maintenance and control of posture and balance requires more attentional resources in dynamic tasks such as walking, compared to static tasks such as sitting or standing quietly (Bardy and Laurent, 1991; Lajoie et al., 1993; Teasdale et al., 1993). Brown et al., (1999) examined responses from both young and older adults asked to respond to a series of unexpected platform displacements while performing a secondary task using a feet in place strategy and a stepping strategy. They found that recovery strategies in response to low velocity disturbances (such as the ankle strategy) were associated with lower attentional demands than strategies for fast velocity disturbances (such as stepping). Furthermore, evidence suggests that secondary attention tasks have a greater effect on postural stability in elderly than young adults (Brown et al., 1999; Rankin et al., 2000; Shumway-Cook and Woollacott, 2000; Redfern et al., 2001). Interestingly, Lundin-Olsson et al., (1997) found that frail elderly patients stop walking when they start talking, reflecting the difficulty of simultaneously performing both a motor and cognitive task. It appears that the complexity of the postural task, along with the cognitive and physical abilities of the subject, affects the ability to allocate sufficient attention to balance when multiple tasks are involved (Lajoie et al., 1993; Shumway-Cook and Woollacott, 2000). If the presence of multiple tasks can affect the risk of falling, I wondered whether it also affects movement strategies and impact severity during an actual fall – the major question addressed by this thesis.

1.3 Objectives

The specific objectives of this thesis work were as follows:

1. To investigate how movement strategies during a sideways fall are affected by involvement in various secondary tasks.
2. To examine how the presence of a secondary task affects the ability of young individuals to utilize specific protective responses during a sideways fall.

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Chapter 2 Sideways falls with and without a secondary task

2.1 Abstract

Fewer than 10% of falls actually cause serious injury (Robinovitch et al., 2000), which suggests that common protective responses exist for avoiding injury during falls (Cummings and Nevitt, 1989). Secondary tasks may alter the nature of these responses. To test this hypothesis, I examined fall dynamics when subjects attempted to "protect themselves" during a sideways fall, and how these strategies were affected by secondary tasks. Thirteen women (aged 18-35) were suddenly released from a sideways leaning position, causing them to fall to their right onto a gym mat. Trials were conducted in each of four conditions: holding a box, holding an empty mug, reciting spoken text, and no secondary task. Pelvis impact was common in all trials (no secondary task = 87%, box = 82%, cognitive = 90%, mug = 79%) and this was unaffected by the secondary task. While the frequency of impact to both hands decreased when carrying an object (box=67%, mug=50% compared to cognitive=90% and no secondary task=85%), 40% of trials in the mug condition involved one hand contacting the ground. The results from this study indicate that the rare occurrence of hip fractures in the young is due to bone strength and the effective use of body segments (such as the hands and knees) to break the fall. These findings indicate that the motor programme which governs falling is robust to the presence of secondary tasks. Apparently, the occurrence of a fall causes a prompt allocation (perhaps due to the startle response) of attentional resources to the task of safe landing, which is performed in a remarkably consistent manner.

Keywords: falls, protective responses, secondary tasks

2.2 Introduction

Falls are the leading cause of death, disability and injury among the elderly. One third of people 65 years or older fall each year (Nevitt et al., 1989; Speechley and Tinetti, 1991; Hayes et al., 1996). Over 90% of hip fractures are the results of a fall (Grisso et al., 1991), and there are about 23,000 cases of hip fracture occurring in Canada annually (Papadimitropoulos et al., 1997).

Risk of hip fracture increases with decreasing mineral density of the proximal femur (Cummings and Nevitt, 1989; Hayes et al., 1996). However, the fall direction and the configuration of the body at impact are at least as important as bone strength in influencing the risk for hip fracture (Hayes et al., 1993; Greenspan et al., 1994; Nevitt and Cummings, 1993). Falling sideways increases the risk for fracture by 6-fold (Greenspan et al., 1994), while impacting on or near the hip increases fracture risk by over 30-fold (Nevitt and Cummings, 1993).

Although falls are common, only 1-2% of falls in the elderly result in hip fracture (Gryfe et al., 1977; Nevitt, et al., 1989; Tinetti et al., 1988) and fewer than 10% cause serious injury (Robinovitch et al., 2000). Furthermore, hip fractures (unlike wrist fractures) due to falls are extremely rare for young adults.

This suggests that common protective responses exist for avoiding serious injury during a fall (Cummings and Nevitt, 1989; Robinovitch et al., 2003). The ability to use these protective responses in real-life may depend on environmental context (e.g., presence of a handrail), behavioural variables (e.g., prior training in falling techniques such as martial arts), and situational variables (e.g., carrying an object) (Bateni et al., 2004; Robinovitch et al., 2003).

The purpose of this study was to determine how secondary tasks such as carrying an object or being engaged in a conversation affect the position and velocity of the body segments at landing from a fall, when the individual is instructed to “fall and protect yourself”. I hypothesized that the secondary tasks would cause a general impairment in fall protective responses, and result in an (a) increase in the frequency of impact to the hip region, and (b) a decrease in the frequency of impact to the outstretched hands.

2.3 Materials and Methods

2.3.1 Subjects

Participants consisted of 13 females between the ages of 18 and 30 yrs (mean = 22 ± 3 yrs) who had mean body weight of 63 kg ± 11 kgs. Subjects were recruited through postings of advertisements at Simon Fraser University and were then screened for eligibility through a telephone interview. Exclusion criteria included a history of impaired balance, neurological disease, uncorrected visual deficit or training in the past five years in balance or safe falling techniques such as gymnastics or martial arts. All participants provided informed written consent and the experimental protocol was reviewed and approved by the Office of Research Ethics at Simon Fraser University.

2.3.2 Protocol

During the experiment, the subjects underwent a series of falls involving sideways perturbations to balance. During these trials the subject stood with her feet shoulder width apart on a rigid platform of 30cm in height. A series of three gymnastics mats similar to those used during athletic high jump were used to cushion falls. Each mat was 240cm X 120cm X 30cm in length, width and height. The mats were placed adjacent and flush to the surface of the floor, providing an effective padded area of 240cm X 360cm (8' X 12') for the subjects to fall on. During the experiment, a tether and electromagnet was used to suddenly release subjects from a sideways leaning position, causing them to fall to their right and onto a gym mat. The subjects were released from a 20-degree inclined position from the vertical (Figure 2-1) as measured by a goniometer.

The only instruction that I provided to subjects was that they should "fall and protect yourself, as if you were landing on a hard surface."

I acquired four trials in each of four conditions (box, mug, cognitive and no secondary task), presented in a pseudo-random order. In the mug condition, the subject carried an empty mug in their right hand that was sealed closed with a lid. In the box condition, the subject carried with both hands a closed empty cardboard box of dimensions 40cm X 20cm X 35cm in length, width and height. No instructions were given to subjects regarding the contents of either object or about whether they should hold or release the object during the fall. In the cognitive task, the participants recited spoken text (a narrated story), which they listened to via headphones.

2.3.3 Data Analysis

An eight camera, 120-Hz motion measurement system (Motion Analysis Inc., CA, USA) was used to acquire 3-dimentional positions of 41 reflective markers placed bilaterally on the shoulder, bicep, lateral elbow, forearm, radial head, lateral wrist, anterior superior iliac spine (ASIS), iliac crest, greater trochanter (GT), front thigh, lateral knee, shank, front shank, lateral ankle, first metatarsal head, fifth metatarsal head and heel as well as single markers on the front head, top head, back head, right clavicle, right scapula, C7 and sacrum. I placed 3 markers on the mats to help determine the time of impact between the subject and a given body part. The time of impact was determined by finding the frame just before a marker on a given body part fell below the mat markers and was determined for the pelvis, knee(s) and hand(s). The occurrence of pelvis impact was taken as the frame where the vertical coordinate of either the right or left GT or ASIS marker descended below the height of the markers on the mat. This was supplemented by analysis to detect the time when the direction of the marker movement changed abruptly, signalling contact. For instance, if the marker was moving downwards and then started to move upwards, the frame just before it started moving upwards would indicate impact. Although both methods were used to determine the time instant during which pelvis impact occurred, priority was given to the former.

In trials when subjects held an object, visual inspection by two experimenters was used to determine whether the box or mug was released before pelvis impact. Kinematic data and custom routines (MATLAB, The MathWorks, Natick, MA, USA) were used to determine the hip proximity angle and impact velocity. The orientation of the pelvis at impact was determined by first establishing the position of a transverse planar ellipse passing through 3 markers: the sacrum, right ASIS and left ASIS (Figure 2-2). Pelvis impact was then determined by calculating the lowest vertical point on the circumference of the ellipse at the time of pelvis impact. The hip proximity angle (α) was then defined as an absolute angle measured within the plane of the ellipse, indicating how close the point of pelvis impact was to the lateral aspect of the pelvis. An angle of $\alpha = 0$ degrees represented direct impact to the lateral aspect to the hip, while positive $\alpha = +90$ degrees reflected impact to the anterior aspect of the pelvis and negative $\alpha = -90$ degrees reflected impact to the posterior aspect of the pelvis. Pelvis impact velocity was determined by taking the average vertical velocity of the right and left greater trochanter markers two frames before impact of the pelvis. Furthermore, I determined the time interval between impact to the pelvis and the first hand to impact and between impact to the right and left hands.

2.3.4 Statistical Analysis

A chi square analyses was used to determine whether differences existed between the various conditions: no secondary task, box, mug and cognitive in the observed frequency of impact to the pelvis, right knee, left knee, right hand and left hand. A one-way analysis of variance was performed to assess whether condition influenced the following dependent variables: hip proximity angle, pelvis impact velocity, time interval between pelvis and first hand to impact, and the time interval between impact to the right and left hand. All statistical tests were run using statistical analysis software (SAS Institute Inc., Cary, NC. Version 5.1) and were based on a significance level of α=0.05.

2.4 Results

Pelvis impact was common in all trials. A chi square analysis indicates that no differences existed between conditions in the percentages of all trials that had pelvis impact (χ^2 (3, N=207)=2.93, p=0.4024) (Table 2-1).

Furthermore a one-way ANOVA indicated that no differences existed between conditions in the mean absolute values of hip proximity angle ($F_{3,12}$=0.65, p=0.5912)

(Figure 2-3). Mean vertical pelvis impact velocity was also unaffected by the secondary tasks ($F_{3,12}$=0.59, p=0.6230) (Figure (2-4)). There was much greater between-subject variability than between-condition variability in pelvis impact configuration and pelvis impact velocity (Table 2-4 and Figures 2-3 & 2-4).

Impact to one or both hands was more common in the no secondary task and cognitive conditions than the box and mug conditions (Table 2-1 & 2-3). Subjects released the box before impact in 73% of trials, and the mug before impact in 32% of trials. When subjects carried an object the frequency of impact to both hands was significantly reduced (box=67%, mug=50% compared to cognitive=90% and no secondary task=85%) (χ^2 (3, N=207)=26.42, p<0.0001) (Table 2-1 & 2-3). Despite releasing the box during 73% of all trials, 20% of box condition trials involved no hand contact. Furthermore, 40% of trials in the mug condition involved one hand contacting the ground at impact and 50% involved both hands impacting. The frequency of one hand contact in the mug condition was more common than in the other three conditions. While this suggests usage of the hands depended on whether subjects were carrying an object and the type of object they were carrying, hand impact was still common. Post hoc tests show that differences in right hand impact occur only in conditions where the box and mug were held (Table 2-2). Differences in left hand impact were due to the box affecting both the no secondary task and cognitive conditions (Table 2-2). During both hands impacting, the box and mug caused differences in all conditions except each other (Table 2-2).

Raw data (Figure 2-5) shows the vertical position of the pelvis along with the right and left wrists from a subject with no hand contact in the box condition and one hand contact in the mug condition. In the box condition, the subject holds the box with both hands while her pelvis and elbows impact. In the mug condition, the subject holds the mug with her right hand and impacts her right elbow and left hand. Complementing these graphs are stick figures (Figure 2-6) which show the descent stages of the fall for the same subject every 150ms.

The average time interval between impact to the pelvis and hand differed significantly between conditions ($F_{3,12}$=5.48, p=0.0040) (Table 2-4) and subjects tended to first impact their hand before the pelvis. The time differences between the pelvis and first hand to impact was less than 50 ms in all conditions except the mug condition. In the mug condition subjects tended to impact the left instead of the right hand, and the interval averaged 63 ± 84 ms.

Chi square analyses indicate that no differences existed between conditions in the frequency of right knee impact (χ^2 (3, N=207)=0.90, p=0.8245) and both right and left knee impact (χ^2 (3, N=207)=3.01, p=0.3903). In all conditions knee impact predominately occurred on the right knee, while left knee impact was infrequent (Table 2-1).

Head impact did not occur during any trials as subjects tended to land on the side of their hip and use their upper extremity and knee(s) to break their fall.

Furthermore, in all trials involving the cognitive task, participants stopped talking immediately after they fell.

2.5 Discussion

This study examined movement strategies during sideways falls where the subject was instructed to "fall and protect yourself", and various secondary tasks (carrying an object, or reciting text) were performed. I hypothesized that subjects would avoid impact to the hip region and instead impact the outstretched hands. I found that impact to the hip occurred in the majority of trials. I also found that impact to the outstretched hands and knee was common. These findings differ from those of Hsiao and Robinovitch (1998) who reported that young adults tend to rotate to avoid hip impact during an unexpected sideways fall.

I also hypothesized that secondary physical or mental tasks would alter the mechanics of the fall in a way that would increase the frequency of impact to the hip and decrease the frequency of impact to the outstretched hands. I found no differences in the frequency of hip impact between no secondary task trials and secondary task trials. I did however observe that frequency of impact to the outstretched hands decreased when carrying an object.

There are noteworthy limitations to the present study and due to safety concerns, our study was limited to young subjects. I examined falling strategies in healthy young adults, and an important question is whether elderly individuals would exhibit similar falling patterns. Safety concerns make it difficult to examine this question experimentally, but it could be addressed through careful post-hoc investigation of real life falls. The limited results that are currently available suggest that attempts to break the fall with the outstretched hands may be less effective among older fallers than among younger adults, due in part to declining strength and reaction time with age (Rice et al., 1989; Nevitt and Cummings, 1993). I examined only sideways falls, since hip fracture risk is greatest for this fall direction (Greenspan et al., 1994). I instructed subjects to "fall and protect yourself", which allowed them the ability to pre-plan their movement strategy before they were suddenly released from the tether. Observed movement patterns therefore reflected at least to some extent subjects' perceptions of what constituted a safe landing. This resulted in considerable variability between subjects in the configuration and velocity of the pelvis at impact. Whether such variability exists in real-life falls is an important question for further study. I prevented them from attempting to recover balance (e.g. by stepping) which may alter movement patterns during a fall (Hsiao and Robinovitch, 1998). Subjects fell onto a compliant mat which likely reduced the fear of injury associated with falling and consequently the nature of observed protective responses. However, I believe that this effect was minimized by instructing subjects to "imagine falling on a hard surface, like a concrete sidewalk". While the occurrence of the fall was unexpected, ensured by randomizing the interval after the "ready" cue when subjects were released, the fall direction was constant. However, subjects participated in four different conditions presented in random order, each requiring intrinsically unique responses.

While impact to the knee(s) and hand(s) did not result in avoidance of impact to the hip, they were probably essential in allowing subjects to avoid impact to the head which was never observed. These impacts also allowed for a sharing of impact energy between the pelvis and extremities, as suggested by the small time differences between pelvis and hand contacts. In all trials except those involving the mug, the average time difference between the pelvis and first hand to impact was less than 50 ms. Previous studies indicate that it takes approximately 50 ms for peak force to be reached after impacting the hip or wrist (Chiu and Robinovitch, 1996; Robinovitch et al., 1991). Presumably, injury risk is largest for falls which exceed this time difference (Hsiao and Robinovitch, 1998), and therefore falls in our mug condition (or a similar real-life situation) may create a greater risk for injury. Subjects dropped the mug in 32% of trials and dropped the box in 73% of trials. Bateni et al., (2004) investigated grasping reactions while holding an object and found subjects held onto the object whether or not it had any stabilization value. They also found that the task of holding an object sometimes prevented subjects from using their arms to grasp a nearby rail for support after experiencing a sudden perturbation to balance. Our results suggest that features of the object (such as perceived fragility, habitual context, and constraints on one versus two hands) influence whether subjects retain their grasp on it during falling.

In summary, I found that sideways falls consistently resulted in direct impact to the lateral aspect of the hip regardless of whether a secondary mental or physical task is present. I also found the frequency of wrist impact decreased when holding an object. I observed considerable variability between subjects in pelvis impact configuration and velocity but remarkably consistent responses for individual subjects across the various conditions. This suggests that a robust motor programme is utilized to facilitate safe landing when falling, and that attentional switching occurs early in descent to facilitate its execution. Future studies should probe further how features and success in executing this programme are affected by task constraints, environmental variable (e.g. obstacles), and age-related changes in sensory, musculoskeletal, and cognitive status.

2.6 Tables

Table 2-1 Percent of all trials involving pelvis, knee and hand impact with corresponding *p* values.

Response	Condition				χ^2	*p* value
	No task (n=53)	Box (n=51)	Cognitive (n=51)	Mug (n=52)		
Pelvis Impact	87	82	90	79	2.93	0.4024
Knee Impact						
Right	75	80	80	83	0.90	0.8245
Left	15	22	12	23	3.01	0.3903
Right and Left	15	22	12	23	3.01	0.3903
Hand Impact						
Right	94	80	96	58	33.40	<.0001
Left	85	67	92	83	11.91	0.0081
Right and Left	85	67	90	50	26.42	<.0001

*Note: *p* values are from chi square analysis with df=3, N=207

Table 2-2 Post hoc results for right hand impact, left hand impact and both hand impact

Hand Impact	χ^2	*p* value
Right Hand Impact		
No Task and Box (N=104)	4.62	0.0316
No Task and Cognitive (N=104)	0.17	0.6786
No Task and Mug (N=105)	19.43	<.0001
Box and Cognitive (N=102)	6.04	0.0140
Box and Mug (N=103)	6.20	0.0128
Cognitive and Mug (N=103)	21.23	<.0001
Left Hand Impact		
No Task and Box (N=104)	4.73	0.0296
No Task and Cognitive (N=104)	1.34	0.2472
No Task and Mug (N=105)	0.09	0.7582
Box and Cognitive (N=102)	10.13	0.0015
Box and Mug (N=103)	3.50	0.0612
Cognitive and Mug (N=103)	2.09	0.1481
Both Hand Impact		
No Task and Box (N=104)	4.73	0.0296
No Task and Cognitive (N=104)	0.67	0.4148
No Task and Mug (N=105)	14.61	0.0001
Box and Cognitive (N=102)	8.35	0.0039
Box and Mug (N=103)	2.94	0.0864
Cognitive and Mug (N=103)	19.77	<.0001

*Note: *p* values are from chi square analysis with df=1

Table 2-3 Percent of all trials showing the breakdown of hand impact.

Type of hand contact	Condition			
	No task (n=53)	Box (n=51)	Cognitive (n=51)	Mug (n=52)
No Hands	6	20	2	10
One Hand	9	14	8	40
Two Hands	85	67	90	50

Table 2-4 Experiment #1: Outcome values.

Variable	Mean ± S.D.	Range	F ratios, *p* Value
Hip Proximity Angle (deg)	—	—	$F_{3,12}$=0.65, p=0.5912
No task (n=13)	-5 ± 24	-55 to 89	—
Box (n=12)	-8 ± 23	-86 to 56	—
Cognitive (n=13)	-7 ± 21	-69 to 82	—
Mug (n=11)	-7 ± 24	-71 to 70	—
Pelvis Impact Velocity (m/s)	—	—	$F_{3,12}$=0.59, p=0.6230
No task (n=13)	-2.1 ± 0.7	-3.2 to -0.1	—
Box (n=12)	-2.1 ± 0.7	-3.1 to -0.6	—
Cognitive (n=13)	-2.3 ± 0.6	-3.1 to -0.2	—
Mug (n=11)	-2.2 ± 0.6	-3.1 to -0.6	—
Time Interval b/w Pelvis and 1st Hand (ms)	—	—	$F_{3,12}$=5.48, p=0.0040
No task (n=13)	3 ± 56	-317 to 117	—
Box (n=10)	23 ± 44	-67 to 92	—
Cognitive (n=13)	1 ± 47	-258 to 117	—
Mug (n=10)	63 ± 84	-200 to 342	—
Time Interval b/w Right and Left Hand (ms)	—	—	$F_{3,12}$=0.75, p=0.5327
No task (n=13)	53 ± 108	-242 to 275	—
Box (n=11)	49 ± 48	0 to 183	—
Cognitive (n=13)	86 ± 67	0 to 442	—
Mug (n=8)	92 ± 141	-92 to 558	—

—, parameter is not applicable for that category.

2.7 Figures

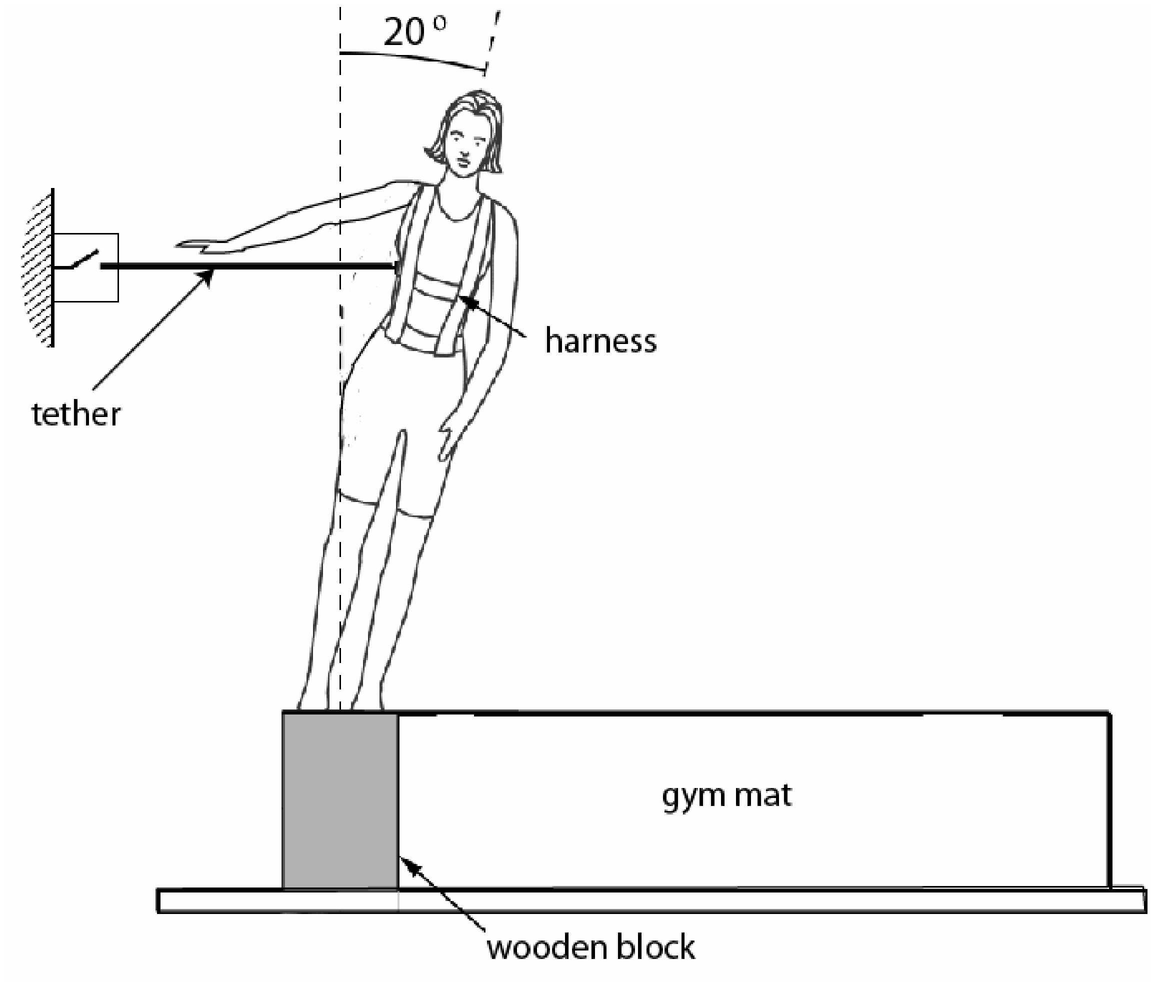

Figure 2-1 Experimental setup. A sideways fall was unexpectedly initiated by releasing a tether, which held the subject at a 20º lean angle.

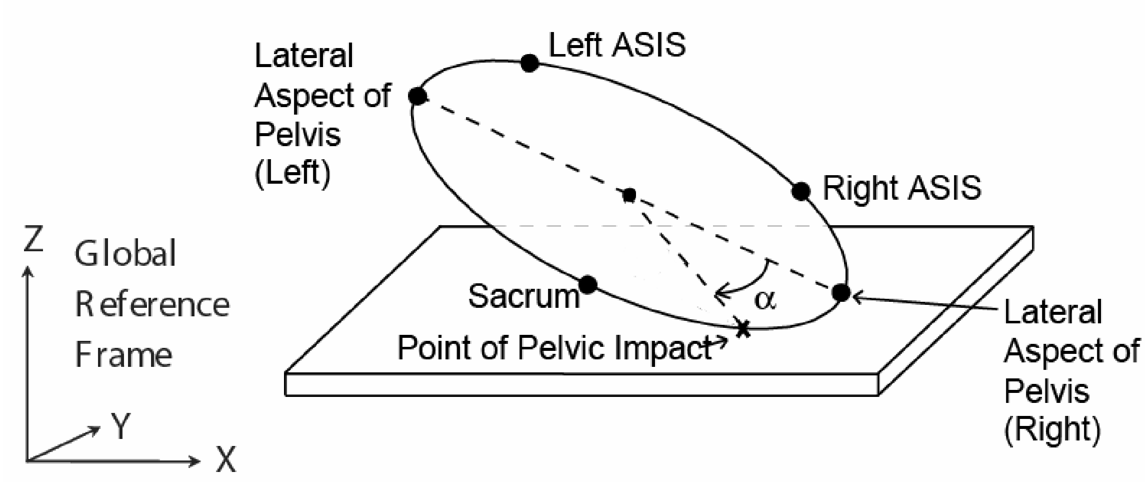

Figure 2-2 Definition of hip proximity angle. The hip proximity angle, which is shown by alpha in the diagram, is an absolute angle that reflects how near the site of pelvis impact is to the lateral aspect of the hip. An angle of 0 degrees indicates direct impact to the lateral aspect to the hip, while +90 degrees reflects impact to the anterior aspect of the pelvis and -90 degrees indicates impact to the posterior aspect of the pelvis.

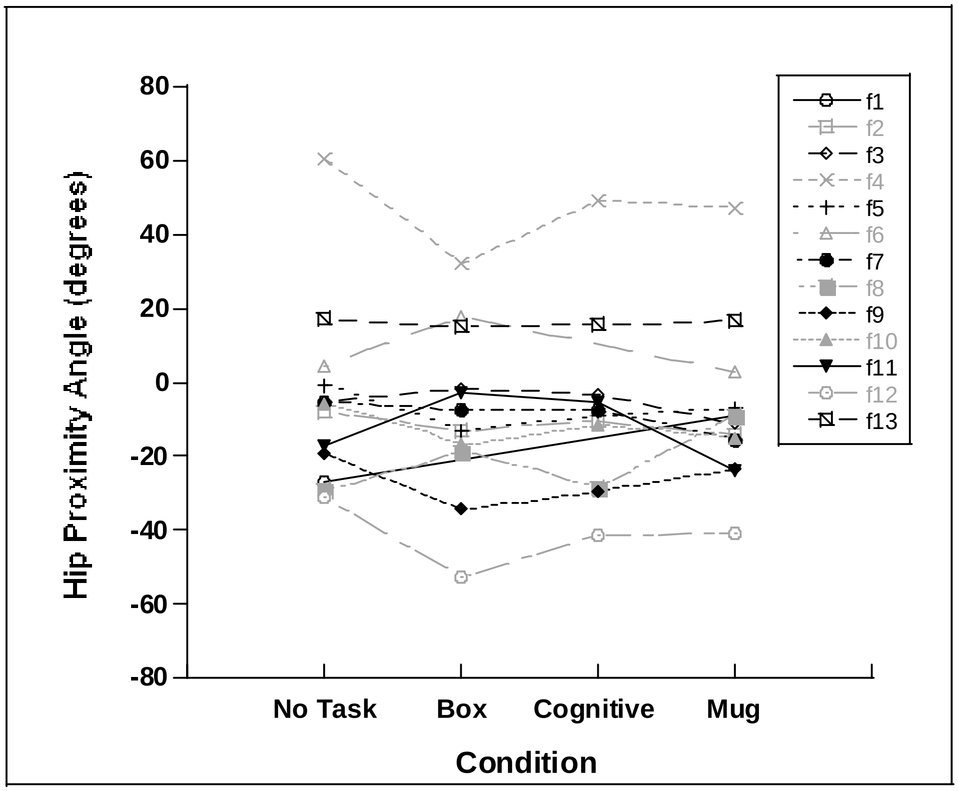

Figure 2-3 Pelvis impact configuration. Impact configurations were unaffected by the secondary task. The distribution of hip proximity angles show considerable variability between subjects, but little variability between conditions.

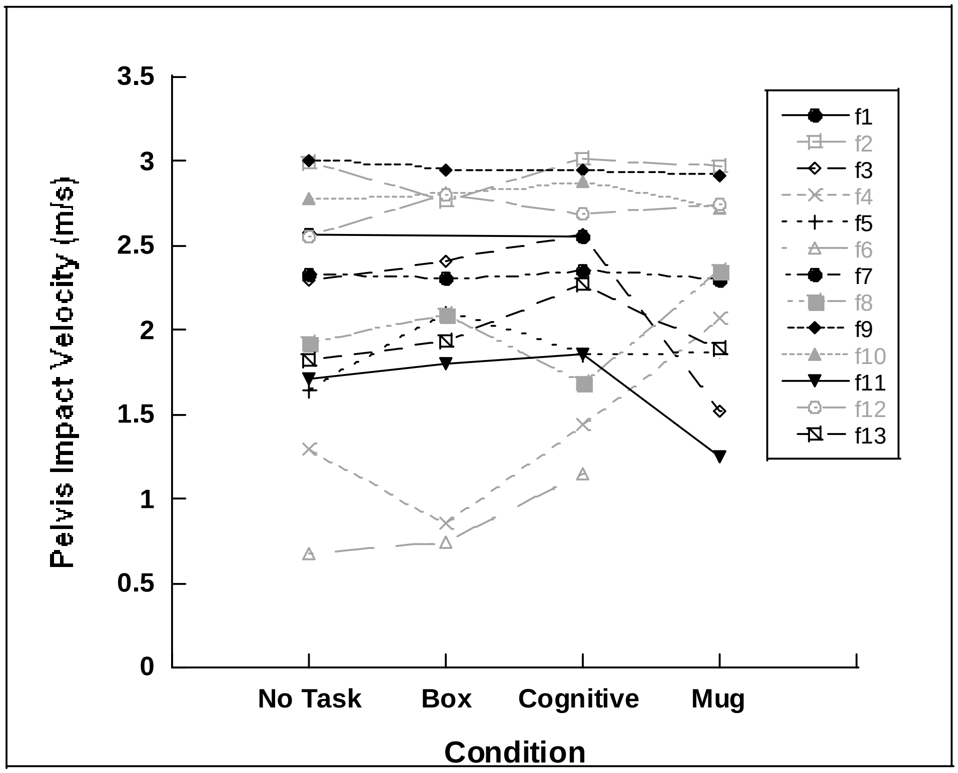

Figure 2-4 Pelvis impact velocity. Impact velocities were not different across various secondary task conditions but there was considerable between-subject variability.

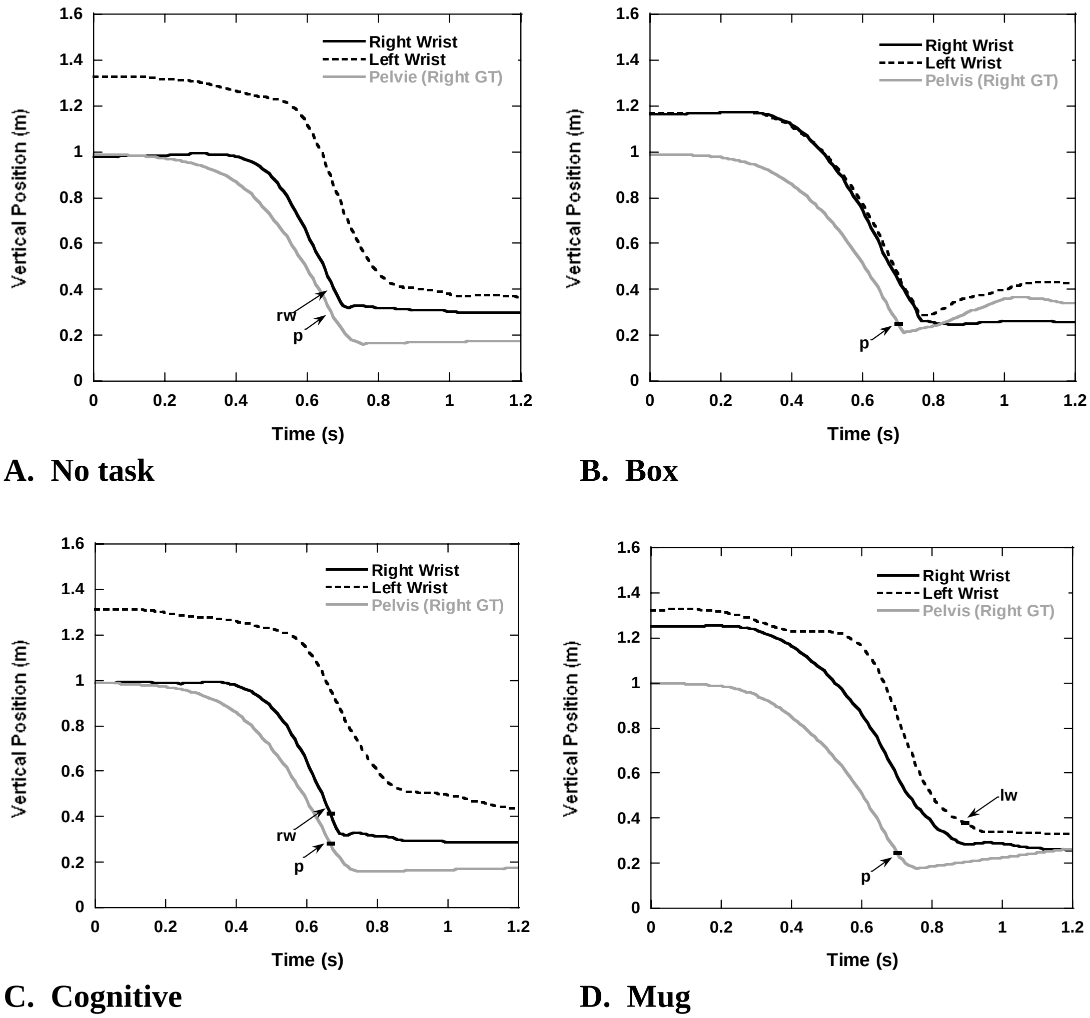

Figure 2-5A-D. **Vertical position of the wrists and pelvis for one subject in all trials. Each trace begins at fall initiation. The letters represent the time of impact: *p* = pelvis impact, *rw* = right wrist impact and *lw* = left wrist impact. Note that in (B), the box trial no hands impacted, which represented 20% of all trials. Also note that in (D), the mug trial only one hand impacted the mat, which was representative of 40% of all trials.**

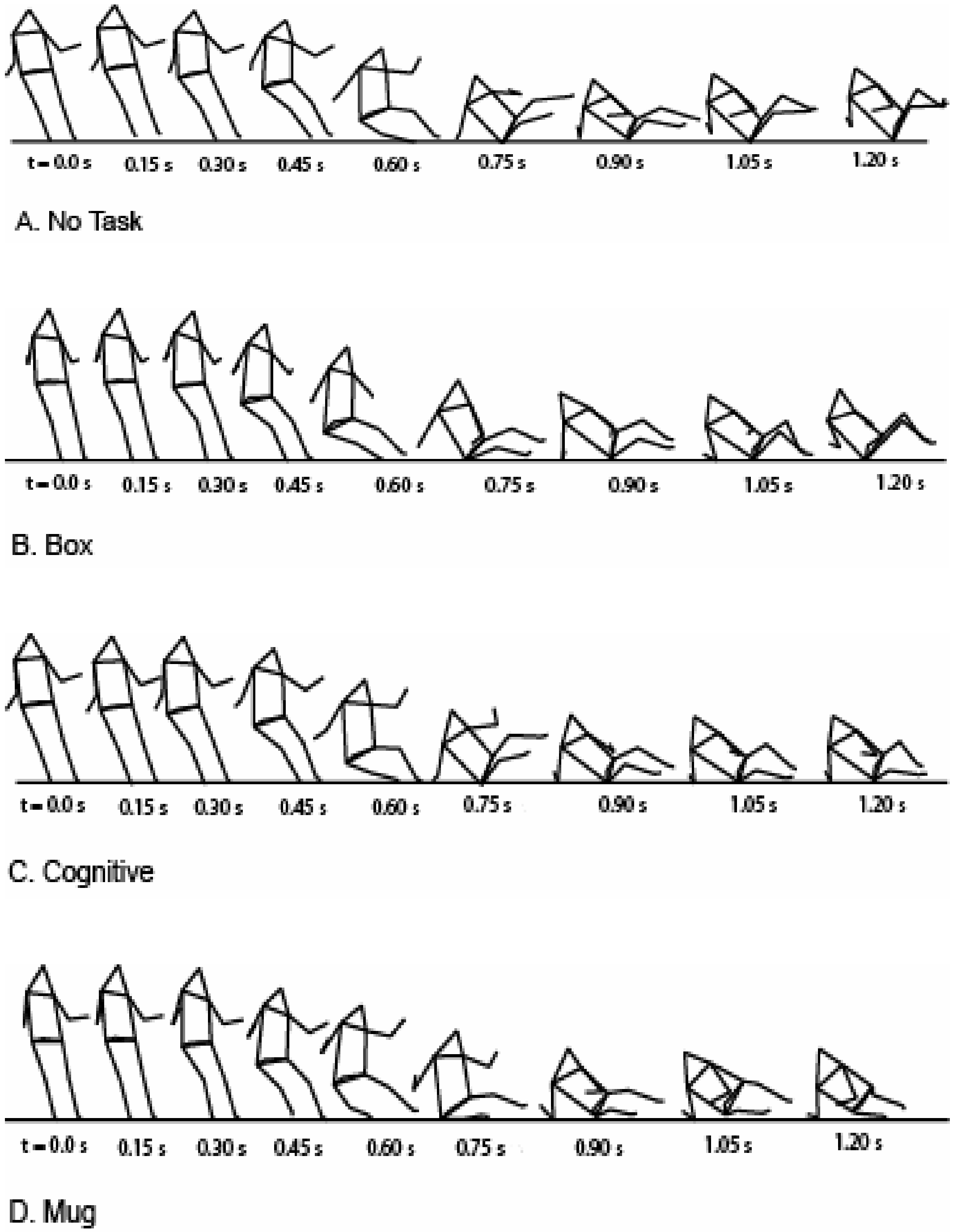

Figure 2-6A-D. **Stick figures showing descent kinematics for one subject. The trials are the same as those used in Figure 5A-D. Pelvis impact occurred in all trials. In (A) a no task trial, the subject lands impacting the ground with the right hand; (B) a box trial, the subject lands with no hands impacting and still holding the box with both hands; (C) a cognitive trial, the subject lands impacting the ground with the right hand; (D) a mug trial, the subject lands impacting the ground with their left hand and their right hand holding onto the mug.**

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Chapter 3 Influence of a Cognitive Task on the Ability to Avoid Hip Impact during Sideways Falls

3.1 Abstract

Recent studies have shown that the maintenance of balance is attentionally demanding and can be impaired by a cognitive task (Brown et al., 1999; Shumway-Cook and Woollacott, 2000). I have investigated whether a cognitive task can affect the ability of young adults to employ a specific protective response (rotating to avoid hip impact) during an actual sideways fall. Nineteen women (aged 18-30) participated in both control and cognitive trials where they were released from a sideways leaning position, causing them to fall to their right onto a gym mat. The site of impact on the pelvis was closer to the lateral aspect of the hip in cognitive trials than in control trials (43 ± 18º versus 51 ± 19º in FR and 59 ± 18º versus 68 ± 18º in BR) (p=0.0006). This was due to a longer delay in the initiation of rotation in cognitive trials (293 ± 60 ms versus 232 ± 71 ms in FR and 278 ± 87 ms versus 239 ± 60 ms), as opposed to a change in mean angular velocity. The results from this study indicate that the attentional demands associated with falling are sufficient enough that involvement in a secondary task can impair one's ability to rotate to avoid hip impact during a sideways fall.

Keywords: falls, attention, cognitive, secondary tasks

3.2 Introduction

Falls are a major health problem for the elderly and are the cause of over 90% of hip fractures (Grisso et al., 1991). While risk for hip fractures depends on bone density, factors associated with the dynamics of the fall are the strongest determinants of fracture risk (Hayes et al., 1993). For example, falling sideways, in comparison to forward or backward, increases the risk for hip fracture by 6-fold, while landing directly on the hip increases fracture risk by 30-fold (Nevitt and Cummings, 1993; Greenspan et al., 1994).

Recent research has shown that young subjects are able to rotate during descent to avoid hip impact during a sideways fall (Robinovitch et al., 2003). In the current study, I examined whether subjects' ability to execute this specific protective response is affected by a secondary attention task. Attention can be defined as the capacity of an individual to process information (Woollacott and Shumway-Cook, 2002). Lajoie et al. (1993) found that as the complexity of the postural task increased, performance on a secondary auditory reaction time task increased. They concluded that as postural tasks become more complicated (such as from sitting or standing to walking), the attentional demands also increase. Accordingly, the attentional demands associated with falling should be significant and the performance of a secondary cognitive task may significantly impair one's ability to execute a specific protective response. On the other hand, as observed in our first study, subjects may prioritize falling and quickly switch attention to the task of executing a specific landing strategy. By examining how a secondary attention task affects subjects' ability to execute a specific protective response – rotating during descent to avoid hip impact – this second study provides information on the attentional demands of falling which complements the results from the first study.

Accordingly, our goal in this study was to examine whether the ability to rotate forward or backward during a sideways fall is affected by a secondary cognitive task. I hypothesized that the secondary task would (1) reduce the ability of subjects to rotate and result in impact closer to the hip, (2) increase the time involved in initiating rotation and (3) increase the impact velocity of the pelvis.

3.3 Materials and Methods

3.3.1 Subjects

Participants consisted of 19 females between the ages of 18 and 30 years (mean = 22 ± 4 yrs) having body weight between 41 and 82 kg (mean = 62 kg ± 12 kgs). They were recruited through postings of advertisements at Simon Fraser University and screened for eligibility through a telephone interview. Exclusion criteria included a history of recent shoulder dislocation, rotator cuff injury, knee ligament repair, severe neck pain, concussion or whiplash, regular episodes of dizziness or fainting, neurological disease, uncorrected visual deficit or participation in sports that involve extensive fall training such as gymnastics or martial arts during the past five years. All participants provided informed written consent and the experimental protocol was reviewed and approved by the Office of Research Ethics at Simon Fraser University.

3.3.2 Protocol

Participants underwent a series of falls involving sideways perturbations to balance. During these trials, participants stood on a rigid platform with their feet shoulder width apart. A series of gymnastics mats of dimensions 360cm wide x 240cm long x 30cm thick, similar to those used during athletic high jump, were located flush to the platform. A tether and electromagnet were used to suddenly release subjects from a sideways leaning position, causing them to fall to their right onto a gym mat. Before release, the subject was inclined 20-degrees from the vertical (Figure 3-1).

Subjects were instructed to fall using one of three different techniques: forward rotation (FR), backward rotation (BR) and no rotation (NR). These instructions were presented to the subject by projecting an image indicating the direction of rotation on the wall in front of them at the same time the fall was initiated. During the FR trials, the subject was instructed to rotate forward during descent to land on the outstretched hands. For the BR trials, the subject was instructed to rotate backwards during descent to land on their buttocks. During NR trials, the subject was instructed to fall sideways with no rotation, to land on her side. If a blank screen was presented to the subjects, a NR fall was indicated. Subjects were instructed to fall according to the image that was randomly displayed to them (FR, BR or NR). Subjects were also instructed to “keep their knees extended during descent”, “land as softly as possible” and “avoid head impact”. In addition, subjects were instructed that the most important thing was to “avoid impacting your hip” during both FR and BR trials.

The cognitive task, which was performed during half of all trials, involved listening to a story via headphones and reciting the spoken text out loud. I wanted a task that would involve both listening and talking in order to simulate a situation similar to an engaging conversation. Subjects were instructed to “continue talking up to the time the tether is released”.

A total of 26 trials were collected; 10 FR (5 control, 5 cognitive) and 10 BR (5 control, 5 cognitive). The 6 NR (3 control, 3 cognitive) trials were ‘catch’ trials, to decrease expectation of rotation and were not analyzed. The direction of rotation and the cognitive task were both randomized. Furthermore, a random time of 1-10 seconds was inserted between the time the subject was in the initial starting position and the instant the tether was released.

3.3.3 Data Analysis

An eight camera, 120-Hz motion measurement system (Motion Analysis Inc., CA, USA) was used to acquire 3-dimentional positions of 41 reflective markers placed bilaterally on the: shoulder, bicep, lateral elbow, forearm, radial head, lateral wrist, anterior superior iliac spine (ASIS), iliac crest, greater trochanter (GT), front thigh, lateral knee, shank, front shank, lateral ankle, first metatarsal head, fifth metatarsal head and heel as well as single markers on the front head, top head, back head, right clavicle, right scapula, C7 and sacrum. I placed 3 markers on the mats to help determine the time of impact between the pelvis and the mat. The time of pelvis impact was taken as the frame where the vertical coordinate of either the right or left GT or ASIS marker descended below the height of the markers on the mat. This was supplemented by analysis to detect the time when the direction of the marker movement changed abruptly, signalling contact. For instance, if the marker was moving downwards and then started to move upwards, the frame just before upward movement would indicate impact. Although both methods were used to determine the time of pelvis impact, priority was given to the former.

Custom routines (MATLAB, The MathWorks, Natick, MA, USA) were used to determine the orientation of pelvis at impact as quantified by the hip proximity angle, the time during descent when pelvis rotation was initiated and the mean and maximum angular velocity of the pelvis during descent. The orientation of the pelvis at impact was determined by first establishing the position of a transverse planar ellipse passing through: the sacrum, right ASIS and left ASIS (Figure 3-4), and then identifying the lowest vertical point on the circumference of the ellipse at the time of impact. The hip proximity angle (α) was then calculated as the angle measured within the plane of the ellipse, which indicates how close the point of pelvis impact was to the lateral aspect of the pelvis. An angle of $\alpha = 0$ degrees indicates direct impact to the lateral aspect to the hip, while $\alpha = +90$ degrees reflects impact to the anterior aspect of the pelvis and $\alpha = -90$ degrees reflects impact to the posterior aspect of the pelvis. The time to initiate rotation during descent was defined as the time after release when the subjects' angular velocity during descent first reached ±0.1deg/s. Pelvis impact velocity was determined by taking the average vertical velocity of the right and left trochanter markers two frames (about 17 ms) before impact of the pelvis. The mean and maximum pelvis angular velocities were derived by differentiating position data.

3.3.4 Statistical Analysis

Statistical analysis was performed using a two-way repeated measures analysis of variance, with two independent variables: direction (with two levels: FR and BR) and cognitive task (with two levels: control and cognitive). A separate ANOVA was used for each of the following dependent variables: hip proximity angle, time to initiate rotation, pelvis impact velocity, mean and maximum pelvis angular velocity. Paired *t* tests were used to further identify the source of any differences. Pearson product moment correlations were used to examine associations between hip proximity angles and times to initiate rotation to see if a causal relationship existed between changes in these two variables. Statistical tests were run using the statistical analysis software (SAS Institute Inc., Cary, NC. Version 5.1).

3.4 Results

3.4.1 Effect of Condition and Rotation on Hip Proximity Angle

A main effect of both cognitive task and direction of rotation on hip proximity angle was found (cognitive task = ($F_{1,18}$=17.44, p=0.0006), direction = ($F_{1,18}$=10.96, p=0.0039). The mean value of the hip proximity angle was lower in the cognitive trials than the control trials by 16% in the FR condition, and by 13% in the BR condition (Table 3-1). Raw data (Figure 3-5A-D) illustrates typical rotational patterns from 4 subjects all of whom demonstrate axial rotation in the cognitive than control trials. The mean absolute value of hip proximity angle was greater in BR trials than FR trials (68 ± 18º versus 51 ± 19º in the control condition and 59 ± 18º versus 43 ± 18º in the cognitive condition) (Table 3-1).

3.4.2 Effect of Condition and Rotation on Time to Initiate Rotation

A main effect of cognitive task on time to initiate rotation was found ($F_{1,18}$=13.52, p=0.0017). The mean value of the time to initiate rotation was greater in the cognitive trials than the control trials by 26% in the FR condition, and by 16% in the BR condition (Table 3-1). There was no main effect on time to initiate rotation for the direction of rotation between FR trials and BR trials ($F_{1,18}$=0.03, p=0.8559).

3.4.3 Effect of Condition and Rotation on Pelvis Impact Velocity

The main effect for cognitive task trials approached significance ($F_{1,18}$=4.35, p=0.0514) suggesting that pelvis impact velocity was lower in cognitive than control trials (2.6 ± 0.3 m/s compared to 2.7 ± 0.3 m/s in FR trials and 2.8 ± 0.2 m/s compared to 2.9 ± 0.17 m/s in BR trials). In addition, a main effect of direction was found as pelvis impact velocity was smaller (Table 3-1) in FR trials compared to BR trials ($F_{1,18}$=15.03, p=0.0011) (Table 3-2).

3.4.4 Correlations between Hip Proximity Angle and Time to initiate Rotation

Correlations were based on differences between the control and cognitive condition for each rotation type. In backward rotation trials, a negative correlation existed (r= -0.51) (p=0.0272) between hip proximity angle and time to initiate rotation. No correlation (r= -0.21) (p=0.3861) was observed in forward rotation trials between hip proximity angle and time to initiate rotation.

3.5 Discussion

Our results indicate that the ability of young adults to avoid impact to the pelvis during a sideways fall is reduced by a secondary cognitive task. In particular, the cognitive task caused a delay in the time for young adults to initiate rotation and resulted in impact closer to the lateral aspect of the hip. While previous research has examined the kinematics of falls (van den Kroonenberg et al., 1996; Hsiao and Robinovitch, 1998; Smeesters et al., 2001; Robinovitch et al., 2003), this is the first study to our knowledge that has examined how an attention demanding task affects specific protective responses during a fall .

I also hypothesized that the cognitive task would affect the severity of the fall by increasing the pelvis velocity at impact. Our results indicate the opposite trend – impact velocities were slightly lower (by about 0.1 ms) in the cognitive condition, when compared to the control. Accordingly, the mechanisms responsible for reducing impact velocity during a fall – such as energy absorption through muscle contraction during descent – do not appear to be sensitive to the attentional task I employed. Similar to Robinovitch et al. (2003) a lower pelvis impact velocity was seen in FR trials compared to BR trials. This difference is likely due to individuals impacting their knees before their pelvis during FR trials, but not BR trials.

This study has several limitations. Unlike a real fall, participants were aware of the magnitude and direction of the perturbation. Furthermore, I used only one type of perturbation, and variations in perturbation characteristics may effect fall kinematics as may neuromuscular variables (e.g., reaction time and strength), environmental variables (e.g., obstacles) or situational variables (e.g., carrying an object). Just after the onset of the fall, subjects were required to view the wall in front of them to acquire a visual cue of the desired landing strategy, which required allocation of attentional resources. Also, subjects fell onto a compliant gym mat, which may have reduced their fear of injury and thus altered their responses. However, any reduction in fear due to falling onto a compliant surface was likely mediated by the fact that subjects were under pressure to rotate correctly. Furthermore, any attempt by the subject to anticipate or pre-plan their response was likely minimized, as subjects were unable to predict between FR, BR and NR options, which were presented randomly.

In summary, I demonstrated that a secondary cognitive task delayed young participants' ability to rotate during descent to avoid impact to the hip during a sideways fall. The mechanism underlying these trends was a delay in the initiation of rotation following release and not a change in subsequent rotational velocity.

3.6 References

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3.7 Tables

Table 3-1 Means, standard deviations and range values for outcome parameters.

Variable	FR Control	FR Cognitive	BR Control	BR Cognitive
Hip Proximity Angle (deg)	51 ± 19 3 to 99	43 ± 18 -49 to 99	68 ± 18 -122 to -8	59 ± 18 -129 to 51
Time to Initiate Rotation (ms)	232 ± 72 50 to 467	293 ± 79 83 to 675	239 ± 60 42 to 458	278 ± 87 33 to 633
Mean Angular Velocity (m/s)	139.4 ± 27.5 34.0 to 231.4	129.0 ± 42.1 -178.9 to 215.0	-138.0 ± 25.1 -230.5 to 147.0	-138.0 ± 26.9 -215.5 to 190.2
Max Angular Velocity (m/s)	1.8 ± 0.5 -1.6 to 4.1	1.9 ± 0.7 -1.9 to 7.0	-1.8 ± 0.4 -3.5 to -0.9	-1.8 ± 0.4 -3.6 to -0.7
Pelvis Impact Velocity (m/s)	2.7 ± 0.3 1.4 to 4.3	2.6 ± 0.3 0.6 to 3.2	2.9 ± 0.2 1.8 to 3.3	2.8 ± 0.2 0.04 to 3.4

Notes: (1) FR = forward rotation, BR = backward rotation; (2) first row cell entries show mean ± one standard deviation followed in the second row by range (min to max)

Table 3-2 Paired *t*-test values.

Variable	*p* Value
Hip Proximity Angle (deg)	—
Forward Rotation: ConFR & CogFR (n=19)	0.0132
Backward Rotation: ConBR & CogBR (n=19)	0.0050
Control Condition: ConFR & ConBR (n=19)	0.0037
Cognitive Condition: CogFR & CogBR (n=19)	0.0100
Time to Initiate Rotation (ms)	—
Forward Rotation: ConFR & CogFR (n=19)	0.0040
Backward Rotation: ConBR & CogBR (n=19)	0.0219
Control Condition: ConFR & ConBR (n=19)	0.7816
Cognitive Condition: CogFR & CogBR (n=19)	0.5230
Pelvis Impact Velocity (m/s)	—
Forward Rotation: ConFR & CogFR (n=19)	0.1300
Backward Rotation: ConBR & CogBR (n=19)	0.0984

— , parameter is not applicable for that category.

3.8 Figures

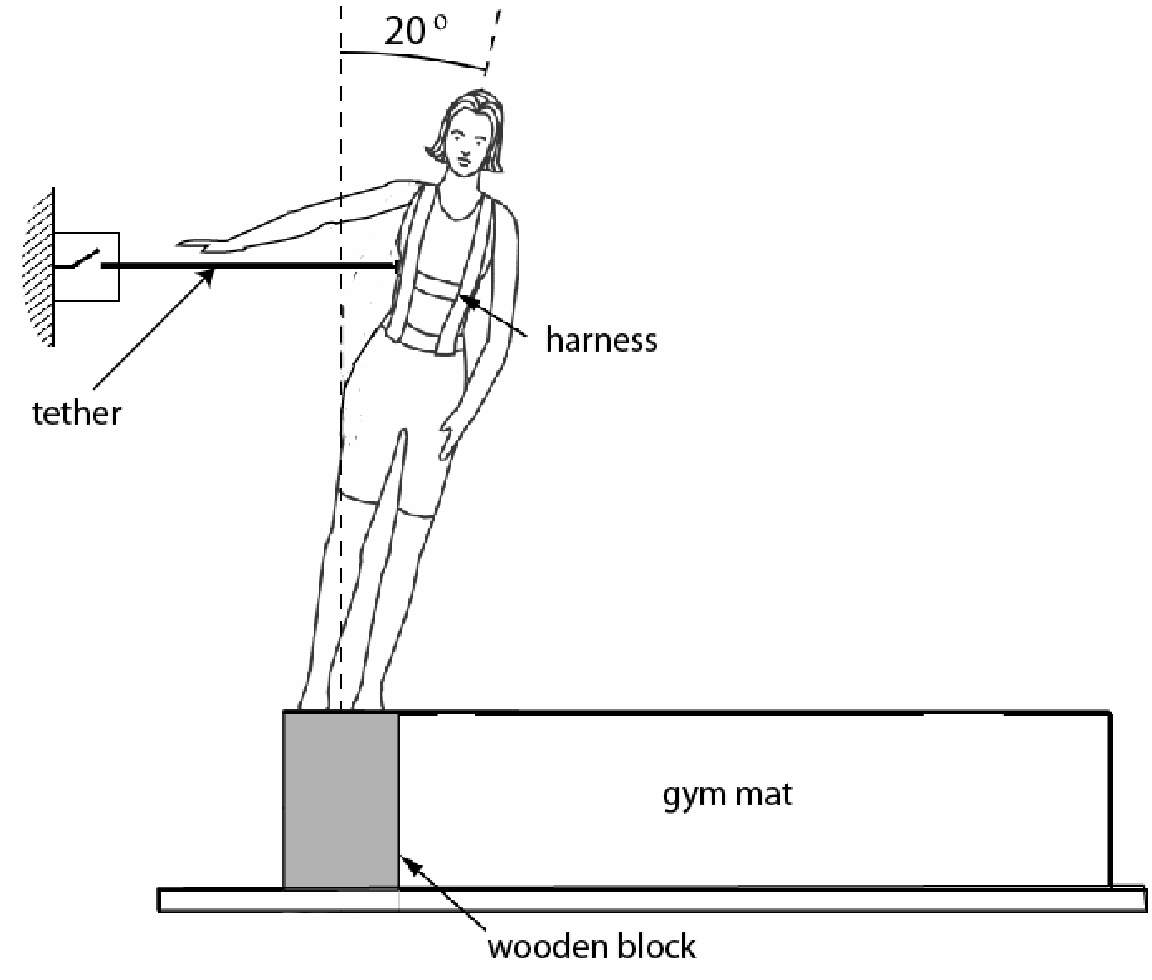


Figure 3-1 Experimental setup. A sideways fall was unexpectedly initiated by releasing a tether, which held the subject at a 20º lean angle.

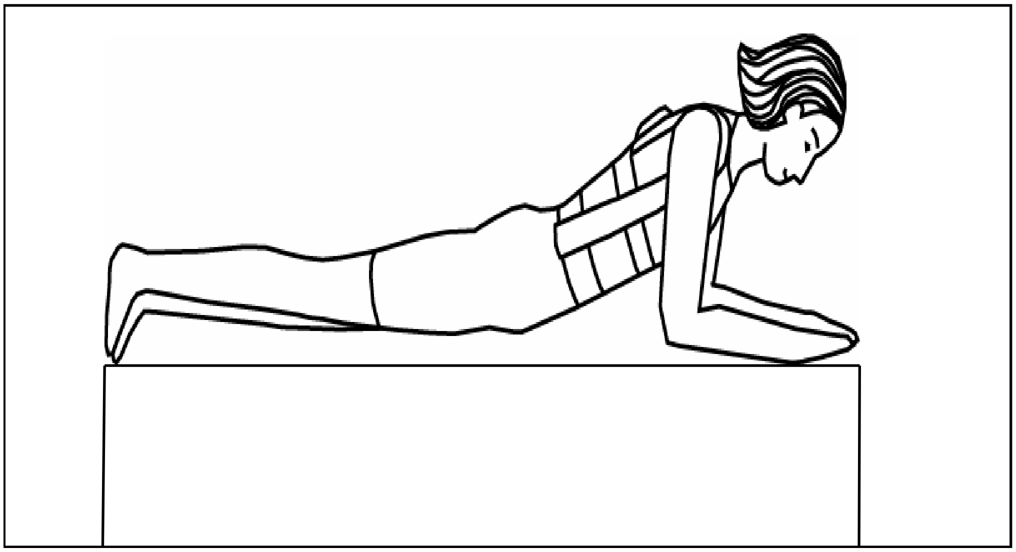


Figure 3-2 Forward rotation. Image presented to subjects at the time of release showing a person landing on the outstretched hands.

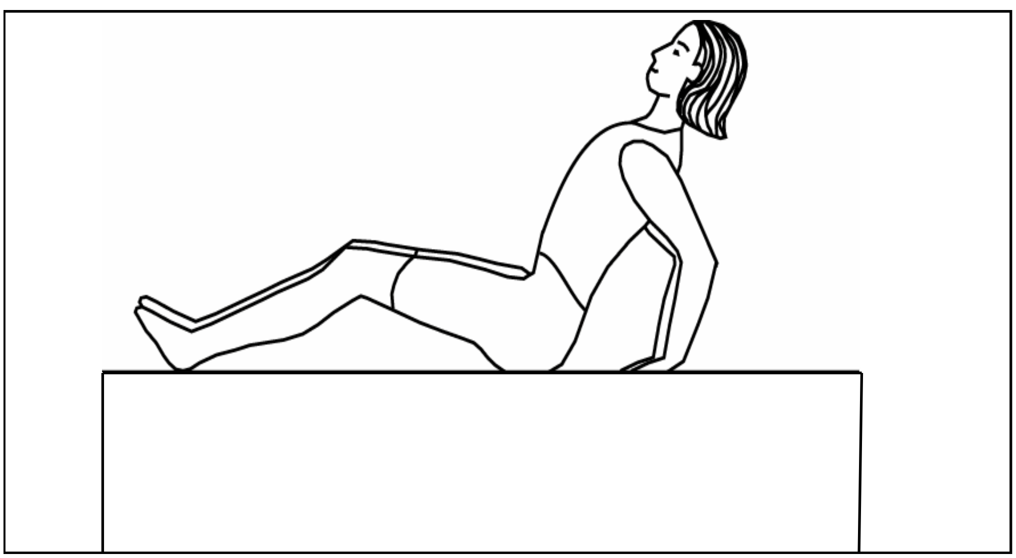


Figure 3-3 Backward rotation. Image presented to subjects at the time of release showing a person landing on the buttocks.

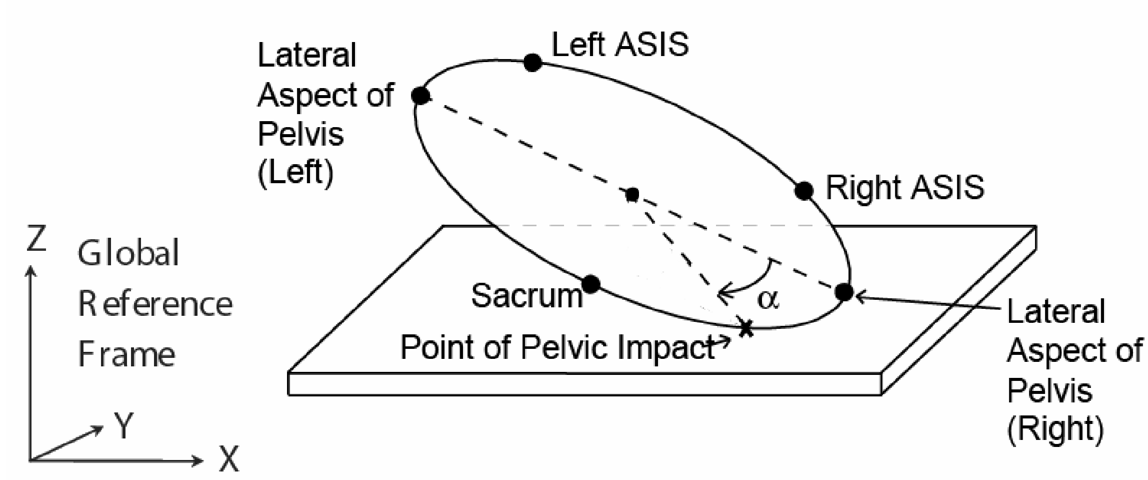
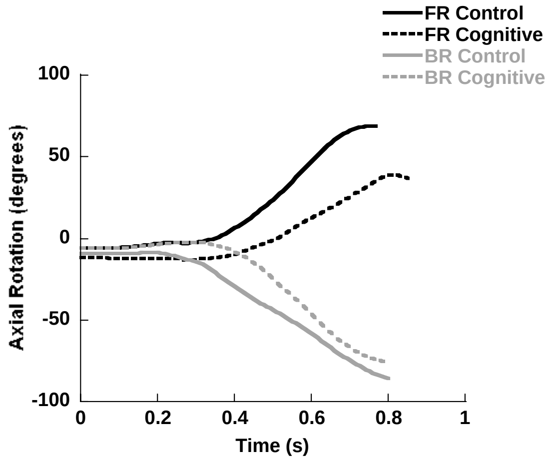
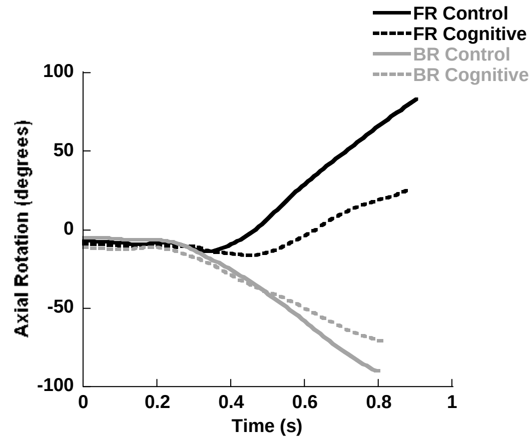


Figure 3-4 Definition of hip proximity angle. The hip proximity angle, which is shown by alpha in the diagram, is an absolute angle that reflects how near the site of pelvis impact is to the lateral aspect of the hip. An angle of 0 degrees indicates direct impact to the lateral aspect to the hip, while +90 degrees reflects impact to the anterior aspect of the pelvis and -90 degrees indicates impact to the posterior aspect of the pelvis.



A. Sub 5



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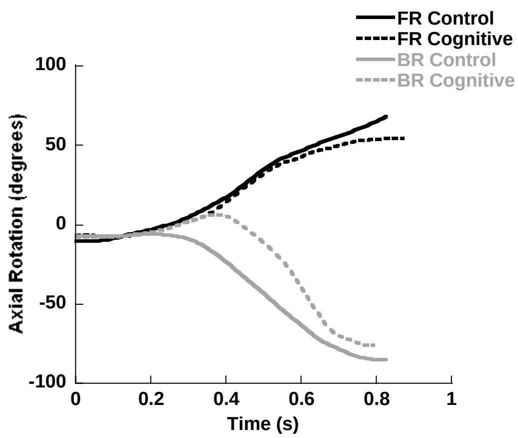
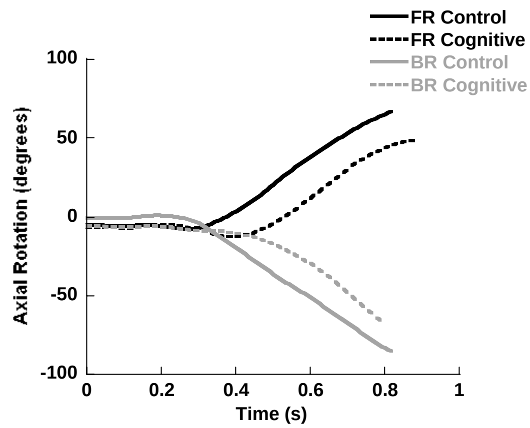


C. Sub 15



D. Sub 18

Figure 3-5A-D. **Axial rotation of the pelvis during descent for four typical subjects in forward rotation trials (FR) and backward rotation trials (BR). Axial rotation at pelvis impact is equal to the hip proximity angle. Each graph begins at fall initiation and ends at pelvis impact. Note that lower axial rotation was demonstrated by all subjects in cognitive trials compared to control trials. Also note that in most cognitive trials there was a delay in the time for subjects to initiate rotation.**

Chapter 4 General Conclusions

4.1 Summary

Falls and fall-related injuries are a major public health problem among the elderly worldwide. With our aging population on the rise, reducing both the incidence and severity of falls is a priority. This thesis examined protective responses that young individuals utilize to land safely during a fall and how these strategies are affected by the performance of various secondary tasks.

In Chapter 2, I discovered that young individuals do not avoid pelvis impact when instructed to land safely but instead use their body segments to break the fall. I found that impact to the lateral aspect of the hip was common in all trials, even those involving a secondary motor or cognitive task. Despite a slight decrease seen in the frequency of hand impact in trials involving carrying an object, impact to at least one outstretched hand was common. Furthermore, head impact did not occur in any of the trials. The results from this study suggest that the rare occurrence of hip fractures in the young is due to some combination of bone strength and effective use of body segments to break the fall.

In Chapter 3, it was shown that involvement in a secondary cognitive task can affect the ability of young individuals to rotate forward (FR) or backward (BR) during a sideways fall. Impact occurred closer to the lateral aspect of the hip in cognitive trials than in control trials. This was due to a longer delay in initiation of rotation in cognitive trials as opposed to a change in mean angular velocity. This suggests that the attentional demands associated with a secondary task can impair subjects' ability to execute a specific safe landing response.

4.2 Limitations

In any fall study, trade-offs exist between simulating a realistic falling situation to evoke natural responses while ensuring participants remain safe. Accordingly, fall studies have included only young subjects, which is a limitation as most fall-related hip fractures occur in older adults.

One limitation of this study was that subjects were aware of the direction and magnitude of the perturbation. Subjects were released from at a 20 degree lean angle by a tether to elicit a sideways fall. This is considerably different from a real-life loss of balance, due to a sudden loss of balance (Nevitt and Cummings, 1993; Robinovitch et al., 2004). Although, falls can occur in a variety of directions I examined only sideways falls, since hip fracture risk increases greatly in this direction (Greenspan et al., 1994). Furthermore, I did not allow subjects to employ balance recovery responses such as stepping.

Another limitation was that subjects fell onto a compliant mat, so any fears associated with falling may have been reduced. However, I believe that this effect was minimized in our first study (Chapter 2) by instructing subjects to: "imagine falling on a hard surface, like a concrete sidewalk".

4.3 Future Work

4.3.1 Secondary Cognitive Task

In this thesis the secondary cognitive task used was a verbal task. It is possible that a secondary task that is spatial in nature, a task that deals with the locations and movements in space might have a greater effect on fall dynamics (Baddeley, 1998). Evidence shows that there is interference between two spatial tasks when performed concurrently as they utilize the portion of the brain responsible for creating and maintaining visual imagery (Baddeley, 1983). This was shown by Alan Baddeley (1983) who found that listening to American football while driving was disruptive. Greater interference may have been noticed in our second experiment (Chapter 3) if a task that was spatial in nature such as the Brooks spatial task (1967) was used. This task involves the participant imagining a 4X4 square and then putting numbers into the appropriate square with specific sentences that provide guidance on the location of these numbers (Quinn and McConnell, 1996). In this case both the postural task (which involves rotating correctly) and the spatial task would be performed by the visual-spatial-sketch pad (VSSP), which is the cognitive system of working memory that would be responsible for delaying response initiation. While a different type of cognitive task might elicit a varied response our goal was to simulate a conversation, which is a situation that occurs frequently in one's day to day life. Future studies may vary the type of cognitive tasks used to examine whether this has an effect on falling behaviour.

4.3.1.1 Cognitive Task Delay

In order to attribute a delay in rotation on the cognitive task in experiment two (Chapter 3), future work should investigate whether this delay is from shifting attention from the cognitive task to the postural task, or due to a lag in processing information about the direction of rotation at the time of release. A future study might examine how individuals rotate while performing the cognitive task when they know their direction of rotation versus when their direction of rotation is suddenly presented to them. This type of study would help decipher if the delay seen in this study (Chapter 3) is strictly due to the secondary task (and is indicative of interference in working memory) or is primarily due to the act of rotating (which the cognitive task might just exacerbate).

4.3.2 Protective Responses in the Elderly

Future research should examine protective responses during falls in older adults. In undertaking such studies, caution must be taken to ensure injuries do not occur. These include having subjects wear hip guards, wrist guards, using a harness to control their velocity during descent and using bone density imaging techniques (such as DXA) to screen out osteoporotic individuals.

4.3.3 Exercise-Based Programs

The use of exercise-based programs to enhance safe landing strategies would complement existing strategies (e.g., hip protectors, fall prevention programs, medications) for preventing serious injury during a fall. However, important goals for future studies are to first identify components of muscular strength, joint flexibility, and reaction time that govern these safe landing responses during a fall. For instance, can individuals be trained to more effectively utilize the outstretched hands during a fall? By collaborating with various health professionals exercise programs can be designed to target these specific factors (e.g., using push-ups to simulate breaking the fall with the outstretched hands) (Robinovitch et al., 2003). By determining these components, exercise programs can appropriately target and modify each of these factors for individuals at risk.

4.3.4 Training under Dual-task conditions

Impairments in the allocation of attention have been shown to be a risk factor for falls (Lajoie et al., 1993; Shumway-Cook and Woollacott, 2000) and researchers have investigated whether such impairments can be diminished with physical practice on balance tasks. Melzer and Oddsson (2004) found that the ability to rapidly execute a step in elderly subjects while simultaneously performing a cognitive task can be improved with training. Additionally, Silsupadol et al. (2006) found that older adults can improve their balance under certain dual-task conditions. This suggests that training under dual-task conditions could minimize the effect of a secondary task and even improve performance on postural tasks.

4.3.4.1 Training Safe Landing Techniques

Only recently, have researchers begun to investigate how individuals can land safely during a fall. Groen et al., (2006) have incorporated martial arts fall techniques, such as rolling after impact into fall prevention training programs for the elderly. Robinovitch et al. (2003) found that individuals can avoid hip impact during a fall by rotating during descent. Future programs should include dual-task paradigms when training individuals on safe landing techniques.

4.4 Conclusions

While preventing falls is paramount to reducing injuries among the elderly, falls are inevitably going to occur, due to factors that may or may not be controllable. Truly understanding how people fall will allow for the design of appropriate strategies targeting fall prevention or safe landing training during a fall. This thesis identified that during a sideways fall movement strategies are utilized to effectively break the fall, even in the presence of a secondary task (Chapter 2). I also identified that the ability to employ specific protective responses is impaired in the presence of a secondary cognitive task (Chapter 3).

4.5 References

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