Effects of Fall Technique Training on Impact Forces when Falling from Standing

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ABSTRACT

As falls and fall-related injuries are a major cause of injuries, the purpose of this study was to investigate whether, and to what extent, the stage combat fall technique training could reduce the impact forces of falls from standing.

Twenty-six healthy young adults (14 males and 12 females) participated in our study, and were randomly assigned to either a training group or non-training (control) group. Both groups completed a pre-intervention and a post-intervention fall testing session, separated by two weeks, in which they performed naturalistic falls. The training group performed identical pre-intervention fall testing as the control group, and was then required to receive four 1-hour training sessions in the course of two weeks, led by a certified stage combat fall technique training instructor. The training group then completed a post-intervention fall testing session where they performed naturalistic falls and also falls using the fall technique they learned. Falls were induced in both forward and backward directions using a tether-release protocol. Differences between control and training groups at pre-training, and group differences in the change in dependent measures with training, were examined using Mann-Whitney U tests.

The results showed that, following stage-combat fall training, the training group exhibited 32% and 35% reduction in median impact forces for forward and backward falls respectively, while the control group exhibited 5% and 2% reductions ($p = 0.002$ and <0.001). In addition, the training

group showed shorter backward fall duration as well as longer impact time, larger impulse, and longer or larger center-of-pressure based measures for both directions of falling than the control group. However, training was not associated with reduced impact force during the naturalistic falls of the training group.

To our knowledge, this was the first study to investigate the stage combat fall technique training and demonstrate its effectiveness as an intervention to reduce impact forces of falls, thereby exploring the potential to reduce the number of fall-related injuries. While these falls were induced from standing, whether these results would transfer to an unanticipated fall while walking due to a slip/trip remain to be explored.

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GENERAL AUDIENCE ABSTRACT

As falls and fall-related injuries are a major cause of injuries, the purpose of this study was to investigate whether, and to what extent, the stage combat fall technique training could reduce the impact forces of falls from standing. Twenty-six healthy young adults (14 males and 12 females) participated in our study, and were randomly assigned to either a training group or non-training (control) group. Both groups completed a pre-intervention and a post-intervention fall testing session, separated by two weeks, in which they performed naturalistic falls. The training group was required to receive four 1-hour training sessions in the two-week intervention period, led by a certified stage combat fall technique training instructor. The training group then completed a post-intervention fall testing session where they performed naturalistic falls and also falls using the fall technique they learned. The results showed that, following stage-combat fall training, the training group exhibited nearly a 1/3rd reduction in impact forces for both forward and backward falls, while the control group only exhibited 5% and 2% reductions respectively. Our analysis also showed that the training group achieved this reduction in impact force by increasing the impact time and spreading out their bodies more, to distribute the impact over a larger area. To our knowledge, this was the first study to investigate the stage combat fall technique training and demonstrate its effectiveness as an intervention to reduce impact forces of falls, thereby exploring the potential to reduce the number of fall-related injuries.

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1. INTRODUCTION

1.1. Falls

Falls and fall-related injuries are major public health problems, especially among aging populations, in modern societies (P. Kannus, Parkkari, Niemi, & Palvanen, 2005). Fall-related injuries are the leading cause of non-fatal injuries and the third leading cause of fatal injuries in the United States (Verma et al., 2016), and the rate of deaths due to falls rapidly rises with increasing age (Sattin, 1992). The expected increases in falls and fall-induced injuries were studied by P. Kannus et al. (2005), who found that 5 million inhabitants in Finland may face more than 2000 fall-related deaths that are projected to increase annually, and that similar increases are also expected to occur in many other Western countries. Alamgir, Muazzam, and Nasrullah (2012) reported that the number of Canadians aged over 65 years who died as a direct result of a fall increased from 3209 during 1997-1999 to 4110 during 2000-2002 with a statistically significant increase in the rate.

As the incidence of falls and fall-related injuries increases, the associated medical costs are likely to rise as well. In 2000, adults aged 65 years or older in the United States experienced 10,300 fatal and 2.6 million non-fatal fall-related injuries that were medically treated and resulted in the direct medical costs of $200 million for fatal and $19 billion for non-fatal injuries (Stevens, Corso, Finkelstein, & Miller, 2006). Later, in 2012, the numbers of medically treated fatal and non-fatal fall-related injuries reached 24,190 and 3.2 million, respectively, that resulted in the direct medical costs of $616.5 million for fatal and $30.3 billion for non-fatal injuries (Burns, Stevens, & Lee, 2016). In the next several decades, the number of older population around the globe is projected to continue to grow, because the baby boom generation after World War II is now entering the older population aged 65 years or older (Ortman, Velkoff, & Hogan, 2014; Vincent & Velkoff, 2010). Hence, the number of fall incidents, fall-related injuries, and following medical costs are all expected to increase since older adults have a high risk of falls and fall-related injuries due to their neurological and musculoskeletal impairments by aging (Pekka Kannus, Niemi, Palvanen, & Parkkari, 2000; P. Kannus et al., 2005).

1.2. Fall-Related Injuries

Falls may induce many adverse outcomes as a result. Up to 10% of falls result in a serious injury (Carpenter, 2010) that leads to hospital admission, long-term care facility admission, disability, and high mortality, which are a major concern in the geriatric population (Kim, 2016). According to Tinetti (2003), falls account for approximately 10% of visits to the emergency department (ED) and 6% of urgent hospitalizations among older adults. Fall incidents among older population may induce increased fear of falling (Narayanan et al., 2009), which can restrict older adults from activities that involve active movements, and loss of confidence and independence, which may lead to admission to a nursing home (Gillespie & Handoll, 2009). In addition, many types of physical injuries have been identified as outcomes of falls, such as sprains/strains, contusions, lacerations, and fractures (Verma et al., 2016). A study by Kim (2016) reported that the body regions majorly injured most often are the head and neck. Another study by Sattin et al. (1990) developed a hierarchy of fall injury whereby hip fracture received the top priority status, followed by skull fracture/intracranial injury, other fractures (e.g., neck, trunk, and upper/lower limbs), and other multiple injuries (e.g., dislocations and open wounds).

Hip fractures are the most serious consequence of falls in older adults (Cumming & Klineberg, 1994), and nearly all fall injury events with hip fracture lead to hospital admission (Sattin et al., 1990). The study in Finland by Parkkari et al. (1999) reported that 98% of all hip fractures was a result of a fall, among patients who experienced hip fractures less than 24 hours before hospital admittance. These hip fractures among older adults are associated with an up to 20% chance of death and a 25% of long-term institutionalization according to their study. Parkkari et al. (1999) reported that most of the hip fracture patients had fallen directly to the side, on the greater trochanter of the proximal femur, and most of the fallers who fractured a hip did not manage to break the falls, like outstretching arms, which indicate that protective responses during a fall may play a significant role preventing hip fractures. Older adults often exhibit increased reaction time and decrease in strength that may decrease the effectiveness of any protective responses they can initiate (Sabick, Hay, Goel, & Banks, 1999). This may help explain why so many hip fractures occur in the older population, as shown in the study by Sattin (1992) that the occurrence of hip fracture increases exponentially by age in older adults. The worldwide annual occurrence of hip fractures is expected to rise to 6.26 million by 2050 (Cooper, Campion, & Melton, 1992); thus, it is critical to develop appropriate interventions for reducing fall-related hip fractures, especially among the older population.

Another common fall-related injury is wrist fracture. Although protective responses or outstretching arms during falls are important to break the falls and reduce impact on hips, such a strategy may instead cause wrist fractures. Among older women, falls with a direct impact onto the extended hand/wrist are the cause of most wrist fractures, and backward falls reportedly have a higher risk of wrist fractures than forward falls (Nevitt, Cummings, & Group, 1993). Wrist fractures are less likely to lead to long-term hospitalization or institutionalization, but they often cause substantial pain, restricted motion, and loss of function immediately (Tan, Eng, Robinovitch, & Warnick, 2006). Such fall-related injuries not only are an economic burden due to medical costs, but also adversely influence qualify of life; therefore, appropriate interventions are necessary to prevent these injuries.

1.3. Risk Factors for Falls

As people become older, they may fall more often for a variety of reasons (Gillespie & Handoll, 2009). Several epidemiologic studies have investigated risk factors for falls, and the risk factors can be categorized as intrinsic and extrinsic (Deandrea et al., 2010). Intrinsic risk factors are individual-specific or patient-related, which include age, gender, disease, muscle weakness, gait and balance disorders, and cognitive impairment. Deandrea et al. (2010) reported that being female is associated with an increased risk of falling, and the study by Alamgir et al. (2012) showed that the proportion of fall mortality was significantly greater among females than males. In addition, Stevens et al. (2006) reported that women sustain hip fractures at a significantly higher rate than men. According to their study, females are more prone to falls and fall-relate injuries because of osteoporosis that disproportionably affects older women. Therefore, many studies recruit female participants to test their interventions. In terms of races and ethnicities, Alamgir et al. (2012) stated that falls mortality rates were high among whites and non-Hispanics than among blacks and Hispanics. In terms of ages, obviously, older adults with frailty (e.g., weaker muscle strengths, lower bone mineral density, etc.) have higher fall risks than younger adults with healthy physical status (Kojima, 2015).

Extrinsic risk factors are external to the patient and generally include physical environment, medication use, environmental hazards (e.g., illumination), and hazardous activities (Choi, Lawler, Boenecke, Ponatoski, & Zimring, 2011; Michael et al., 2010). Kim (2016) reported that in the Republic of Korea, a residential area was the most common location for fall-related injuries that occurred indoor for older adults. The studies by Cumming and Klineberg (1994) and Carpenter (2010) also showed that most falls occurred in older adults' home. Falls are one of the leading causes of injuries and/or deaths occurring in the home environment (Runyan et al., 2005) where older adults tend to stay and spend most of their time, because of their physical frailty (i.e., weakness, impaired balance, and abnormal gait) (Kojima, 2015) and unemployed status (Kim, 2016).

Other than the intrinsic and extrinsic fall risk factors, the likelihood of sustaining fall-related injuries is also influenced by the location, direction, and magnitude of loads applied during the impact stage of the fall. This in turn depends on the position and velocity of the body segments at the moment of impact and could determine severity of injuries (Robinovitch, Brumer, & Maurer, 2004). Older adults who fall on the hip or near the hip are more likely to experience hip fractures and who fall on the hand or arm are more likely to experience wrist fractures (Nevitt et al., 1993). When landing on a hip or wrist, the kinetic energy created due to a fall concentrates on the landing body region, and most older adults cannot avoid fractures due to their low muscle strengths and bone mass. The direction of the fall is also an important determinant of the risk of fracture during a fall and the type of fracture resulted. Proximal humerus, elbow, and wrist fractures may occur in obliquely forward fall direction (Palvanen et al., 2000). Lastly, as magnitude of loads increases, the possibility that one will experience fall-related injuries also increases.

1.4. Biomechanical Parameters for Falls

Many parameters to quantify the severity of falls have been identified by researchers. According to the meta-analysis by Moon and Sosnoff (2017), one of the most frequently reported fall impact severity parameters is impact force, and other secondary parameter to quantify impact severity included fall duration. Impact force represents the external load at impact, while fall duration indicates the time course of the fall. The parameters at impact are investigated at hip, hand/wrist, elbow, shoulder, and neck.

In the study of the martial arts fall technique (MAFT) by Weerdesteyn, Groen, van Swigchem, and Duysens (2008), impact force was used to compute effects of the MAFT on inexperienced subjects after a 30-minute training session. Impact force was defined as the initial peak force in the vertical direction at impact. Fractures were defined to occur if the impact force exceeded the threshold that bones can endure before they break. Another study of the MAFT training among older adults by B. E. Groen, Smulders, De Kam, Duysens, and Weerdesteyn (2010) used fall duration, or time between fall initiation and initial impact, to determine if the five weekly sessions of 45-minute MAFT training led to any changes in fall duration, compared to natural falls. The review on the safe landing strategies during a fall by Moon and Sosnoff (2017) stated that longer fall duration could give people more time to perform fall protective responses, such as outstretching arms, during a fall and thus possibly reduce the risks of fall-related injuries.

In order to determine if one is at more risk of falling, studies have used center-of-pressure (COP) based parameters to quantify one’s postural steadiness. Prieto, Myklebust, Hoffmann, Lovett, and Myklebust (1996) used those parameters to evaluate balance during quiet standing, which included total excursion and 95% confidence ellipse area. Total excursion was defined as the total length of the resultant COP path from medial-lateral (ML) and anterior-posterior (AP) directions, travelled during a quiet standing trial. Similarly, 95% confidence ellipse area was the area of the 95% bivariate confidence ellipse that contains 95% of the resultant COP path. Another method to quantify sway area is to compute the rectangle area of the COP path, to estimate postural steadiness. Rectangle area can be calculated by first computing lengths in ML and AP directions from subtracting max data point by min data point in each direction and then multiplying those lengths together. While these COP-based measures have been used during quiet stance, they could potentially also be employed during falls, to understand fall patterns and strategies.

1.5. Fall Technique Training

The meta-analysis by Moon and Sosnoff (2017) listed a total of six landing strategies – squatting, elbow flexion, forward/backward rotation (for sideways falls), MA falls (rolling and slapping), relaxed muscles, and stepping. Each strategy has distinctive advantages on reducing impact severity; thus, an appropriate technique should be selected considering the unique benefits of each landing technique.

For a squatting strategy, Robinovitch et al. (2004) explained that “squatting during descent” did not mean to simply collapse the knees and hip into full flexion during descent, but rather to flex the knees and hips while contracting the muscles at these joints, as to slow the speed of descent during sitting. The result of their study showed a substantially lower impact velocity and kinetic energy when the squat response was utilized as opposed to non-squat response (i.e., full extension of knees and hips during falls). However, they stated that the protective value of the squat response depends on reaction time (i.e., how quickly one can initiate the response during descent), in addition to strength and flexibility, as increases in the initial lean angle of the body led to a reduction in joint energy absorption and a subsequent increase in impact energy. They also found that the squat response was less effective in reducing impact velocity during falls caused by sudden loss of balance than during self-initiated falls, which indicate its less effectiveness in real life falls and necessitate further studies.

Whereas the squatting strategy uses flexion of lower extremity, an elbow flexion strategy uses flexion of upper extremity or elbows. Chou et al. (2001) explained the elbow flexion strategy as to extend elbows at impact, but then flex immediately, as if in the initial downward phase of a push-up exercise. They showed that the action of elbow flexion could decrease the maximal axial force of elbow and delay the time of peak; thus, it can provide enough time to adjust and avoid the injury. However, they also suggested further studies of falls onto outstretched arms to better understand how upper extremity injuries are related to such falls, as it might cause arm injuries. Squatting and elbow flexion reduce impact velocity and force through absorption of energy in the eccentrically contracting muscles of the lower and upper extremities (Chou et al., 2001; Robinovitch et al., 2004). Hence, sufficient muscle strength in the extremities are essential to maximize the effectiveness of these strategies. Squatting and elbow flexion may therefore have questionable effectiveness among older adults who have less muscle strength than younger adults.

Forward or backward rotation strategies enhance energy distribution by increasing the contact area of the body, which could result in a reduction of impact severity. Robinovitch, Inkster, Maurer, and Warnick (2003), in their study on strategies to avoid hip impact during sideways falls among young women, reported that subjects were able to avoid hip impact by rotating forward or backward during a sideways fall and thereby lower the risk for hip fracture. Rotating forward during descent has the advantage of allowing visualization of the impact surface to coordinate landing, but it generally creates the need for impacting the ground with the upper extremities to prevent impact to the head, which in turn increases one's risk for injury to the wrist, elbow, or shoulder. On the other hands, by rotating backward during descent, one may presumably avoid impact and injury to the hip, head, and upper extremities, but greater energy must be absorbed by the skin, fat, muscle, and skeletal structures of the pelvis than forward rotation, according to their study. Further studies are required to evaluate the appropriateness of the forward and backward rotation falling strategies for frail older adults.

MAFT training involves a rolling movement and a subsequent slapping onto ground after the rolling. MA rolling distributes the impact forces applied to the body along the contact path while rolling. After the MA rolling, arm is used to break the fall by slapping onto the ground. The study by B. Groen, Weerdesteyn, and Duysens (2008) tested three different fall techniques – the "natural" block fall technique that uses an outstretched arm to break falls and the MAFT with and without use of an arm slapping. They showed no differences between a MAFT with or without use of the arm slapping in terms of hip impact force and velocity from kneeling height, suggesting that hand impact played no essential role in protection of the hip in the MA technique. Although MA slapping does not show any difference in impact severity, the study reported that the strategy is essential to maintain stability during MA rolling. Weerdesteyn et al. (2008) reported that older adults could learn the MAFT within five 45-minute training session, and some of them said they had used the technique in a fall in daily life. However, further studies are necessary to quantify the benefits of this technique in terms of impact force reduction after the short training, and to investigate whether extensive training is required if the result from the short training is not significant.

Relaxed muscles strategy involves falling with the body as relaxed as possible without resisting against the fall, and may result in less vertical trunk angle at impact and thus reduce the energy absorbed by the hip (Moon & Sosnoff, 2017). The effectiveness of this strategy on reduction in impact severity during falls is still controversial since it showed a significant reduction in impact velocity in some studies, like one by van den Kroonenberg, Hayes, and McMahon (1996), while showed no significant reduction in other studies, like one by Sabick et al. (1999), as compared to muscle-active or tensed falls. Further research is required to better understand the relaxed muscle strategy as an intervention to reduce fall-related injuries.

Stepping strategy involves repositioning the foot in a more anterior/posterior or lateral position during a descent and enables better preparation for safe landing. It increases fall duration, consequently allowing for enough time to adjust and avoid injuries. The study on protective responses by Feldman and Robinovitch (2007) reported that even unsuccessful attempts to recover balance through stepping were observed to be beneficial in reducing impact severity and hip fracture. However, the stepping strategy may be restricted to older adults due to neurological impairment by aging that elongates reaction time.

Although many different types of fall training programs have been introduced by researchers and tested in many studies, most of the studies have limitations that may hinder application of such fall training programs. Many studies used self-initiated falls from kneeling to determine effects of training due to safety purposes for participants. However, self-initiated falls from kneeling do not represent real life falls that people may experience in everyday life, and efficacy of training on a fall program might not be as efficient when implemented in falls from standing as when implemented in self-initiated falls. Although the differences between the techniques will likely remain since underlying mechanism of different fall techniques is similar in unexpected falls and self-initiated falls (B. Groen et al., 2008), further studies are necessary for induced falls that resemble falls in real life. In addition, many studies have tested falls from a kneeling position, rather from a standing position, due to safety reasons as well. B. Groen et al. (2008) reported that the linear regression model for the MA technique from standing height seemed not different from the model for the MA technique from kneeling height in the single subject who has years of experience in the MAFT. In order for this assumption that the principles and working mechanism of MA falls are similar for falls from standing and kneeling height to be more validated, larger sample size, without prior experiences in fall techniques, is needed. Lastly, most studies have tested their fall interventions to young adults without health or medical conditions. The ultimate goal of these fall prevention programs is to reduce fall-related injuries in the older population with neurological and musculoskeletal impairments. Further studies should be performed to test the effectiveness of such programs when implemented in the older population.

1.6. Stage Combat Fall Technique (SCFT)

SCFT training is for stage combat actors who play stunts or fight choreography. For fighting scenes, actors need to practice numerous times to make realistic scenes while not actually hurting any actors. In addition, how individual actors react to fight moves (e.g., punches, kicks, and throws) is also important to not injure themselves. For this reason, stunt actors are required to learn a fall technique that allows them to fall safely with less impact severity.

Stage combat for plays requires actors to fall in various directions (i.e., forwards, backwards, and sideways), and unique fall techniques for each direction are taught to the actors for safe landing. The technique uses a sliding movement, rather than a rolling movement used in the MAFT, during a fall and avoids impact with the body regions, especially pelvis, where serious injuries can occur. Cara Rawlings, an associate professor in School of Performing Arts at Virginia Tech, describes its mechanism as “spreading peanut butter on breads” and trying to move the pelvis to the ground as soon as possible by lowering and sliding the body horizontally, rather than vertically. The SCFT is not only used in self-initiated falls, when actors fall to avoid collision with other actors or objects, but also used in induced falls, when actors fall as other actors or objects collide with them. Therefore, the SCFT can be used in falls in daily life of any situations to prevent one from fall-related injuries.

Rawlings explains that students in School of Performing Arts learn the fall technique on a “real” floor, like concrete, without mats because there would not be mats on the stage floor when they perform shows. Therefore, the fall technique used in stage combat scenes should help reduce the risk of fall-related injuries as it tries to decrease impact force with floor by redistributing the body’s momentum more towards the horizontal direction and hence reduce the vertical impact force, while the MAFT tries to distribute vertical impact force over a larger area (i.e., by slapping arms) rather than reducing the force. In addition, Rawlings mentions that the fall technique is the extension of “natural” response to falls because falls should look real when performed on stage, so it may be easier and more adaptive for people to implement this technique in their lives. As per her description, we hope to see the effectiveness of the SCFT on reduction of impact severity with our study and further research in the future.

1.7. Aim, Hypotheses, and Anticipated Findings

Although falls and fall-related injuries are prevalent, many of them are preventable. Many proper falling strategies have been introduced as the interventions, but not much information is available regarding the performing arts techniques. Given this lack of literature on the techniques used in performing arts as an intervention to reduce fall-related injuries, the purpose of this study was to investigate the effects of one of the popular performing arts techniques or SCFT. Our specific aim was to quantify the effects of the SCFT on impact forces of falls from standing among healthy young adults. We hypothesized that (1) falls using the SCFT will show lower impact forces, compared to the falls using natural reactions, and (2) the SCFT training will reduce impact forces when falling naturally, compared to the natural falls without training. Any changes in impact forces will be used to predict changes or reduction in fracture risk, resulting from the SCFT training. We believe that the SCFT training will help reduce fall-related injuries that may occur in daily life, across all ages. Once the proof-of-concept for this training is established in the proposed work, future work will need to examine the retention of training effects, explore the dose-response relationship of the training, and investigate this training among older adults.

2. METHODS

2.1. Participants

A convenience sample of 28 participants (18-30 years old, 14 males and 14 females) was recruited from the university and local community, using flyers posted around campus, announcements in classes, and email listservs. However, two female participants quit after the first experimental session due to musculoskeletal soreness. Mean (SD) age, stature, and body mass of the 26 participants were 23.3 (3.6) years, 168.6 (7.0) cm, and 65.1 (11.5) kg, respectively. Inclusion criteria required participants to have no self-reported current or recent (past 12-month) medical conditions or injuries that might affect their natural reactions to falls. Although our ultimate goal is to apply this training to older adults, this initial study focused on young adults to minimize risk of injury. The study excluded anyone who has prior experiences in any other fall technique trainings. In addition, females who are pregnant and obese individuals (body mass index, or BMI ≥ 30 kg/m^2) were excluded to minimize other factors affecting fall behaviors. Due to the lack of data in the literature for such experiment and analysis, a formal sample size analysis was not performed. All participants provided written informed consent prior to participation, and the study was approved by Virginia Tech Institutional Review Board.

2.2. Experiment Overview

The experiment included one pre-intervention fall mechanics testing session, four SCFT training sessions, and one post-intervention fall mechanics testing session. Twenty-six participants were pseudo-randomly allocated and gender-balanced to either a Stage Combat (SC) group (n = 13) or a control (C) group (n = 13). The SC group was required to attend all four SCFT training sessions to be compliant with the study. The C group was not exposed to any intervention but asked to fully rest for at least three days before the post-intervention session. The fall mechanics testing sessions evaluated four impact-force-based dependent variables (i.e., impact force, fall duration, impact time, and impulse) and three COP-measure-based dependent variables (total excursion, 95% confidence ellipse area, and rectangle area) on a thick soft mat placed over the three force platforms, during the falls from standing that were induced by unexpected release from a static lean.

2.3. Experimental Setup

For both pre- and post- interventions fall mechanics testing sessions, the same experimental setup was used. We used a tether-release method, similar to the setup used in one of the past fall studies (Tan et al., 2006). Participants wore a waist belt that has a tether attached to it, and the tether was sustained at preset initial lean angles that were measured from the participants' normal standing angle. In order to create an environment where participants could not anticipate when they would fall, they were asked to stare at the picture attached on the wall they were facing while they were leaning against the waist belt. Then, the participants were released when the investigator randomly released the lock that was holding the tether between 5 – 20 seconds. The fall platform we used for the fall testing is shown in Figure 1. Participants stood on the stack of little thin pads, which was placed over multiple sheets of wood to make it the same level as the falling mat. The falling mat was 243.84 x 121.92 x 30.48 cm large, and it was placed over the wooden platform of the same width and length but the different thickness, 10.16 cm. The wooden platform had three force platforms beneath, which were snugly fit into the space provided underneath the wooden platform, so that the three force platforms would be secured and stay in place even when subject to repetitive falls performed by the participants. To make sure all force platforms made full contact with the wooden platform, two extra sheets of wood with 1.91 cm thickness were placed over the two smaller force platforms. In addition, shims were used to make sure the fall platform is leveled with the floor. For falls from standing, the tether attached on the waist belt was attached to a little metal ring, and the ring was locked by a releaser that was hung at the lean platform at participants' waist level. For the fall testing, participants were asked to wear athletic shoes, shorts, and a tank top that are tight enough that the reflective markers would stay on the original locations attached, before starting the fall testing, even after repetitive falls. Participants were asked to wear the same athletic shoes for both testing sessions, to control for any possible effects of shoe type on fall mechanics.

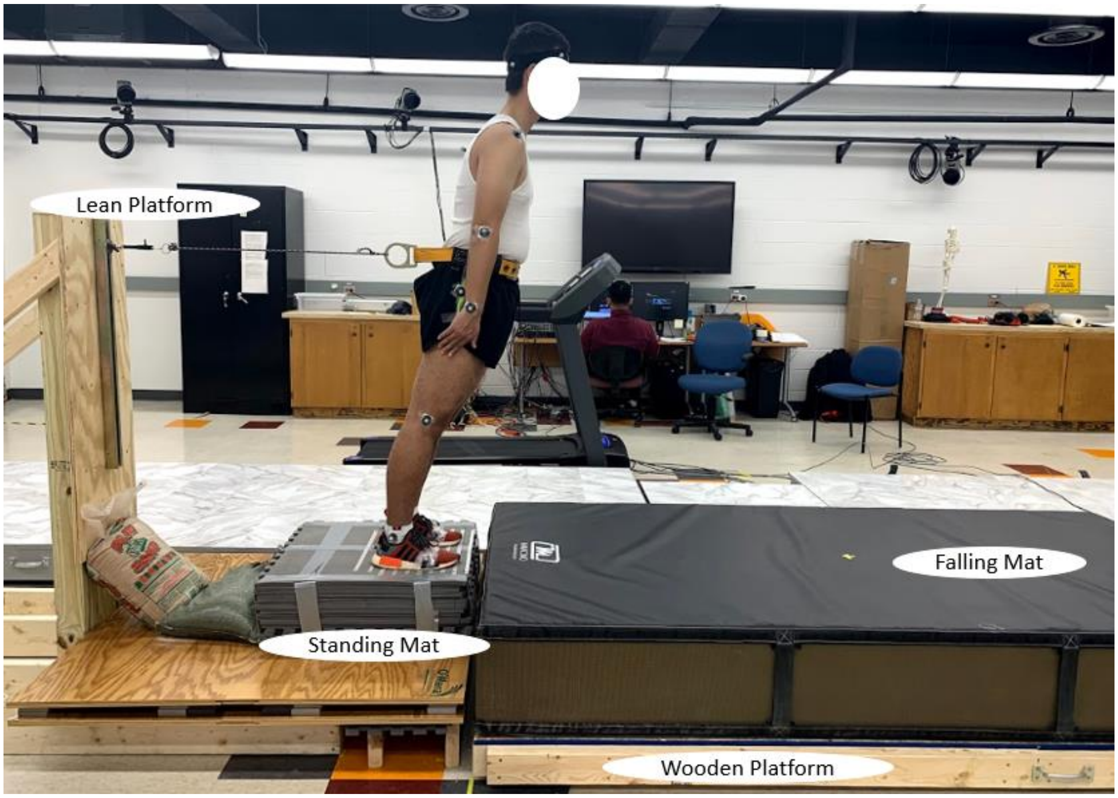

Figure 1. Setup used for forward falls from standing, with initial angle of 15˚. Setup for backward falls from standing was similar; the lean angle was set to 10˚, and participants were facing the opposite direction instead.

2.4. Protocol

2.4.1. *Fall Mechanics Testing Sessions*

During the pre-intervention fall mechanics testing session, we measured and recorded the basic information, such as age, gender, height, and weight. The weight was measured by using both a scale and the three force platforms installed underneath the falling platform by having participants to stand in the middle of the falling mat. Falls from standing was induced by releasing participants from forward and backward static leans using the tether-release mechanism. The tether sustained participants with lean angles of 15˚ for forward falls and 10˚ for backward falls, which were determined based on previous studies to represent lean angles that just exceed the capacity of young adults to recover from falling by taking a step (Hsiao & Robinovitch, 1999, 2001; Tan et al., 2006). First, we measured the participants' normal standing angle, using a goniometer attached to a 1.5 m long metal stick, which measured the angle of the line that connects the reflective markers on a shoulder and an ankle, in respect to the ground. Then, after making sure that the tether is attached to the lean platform, participants were asked to move their feet to the designated location marked on the standing pad and position their feet parallel to each other with shoulder-width wide. The tether level was checked to make sure it is holding the participants at the horizontal level. Lastly, participants were asked to fully lean against the wait belt, and the lean angle (i.e., 15˚ for forward falls and 10˚ for backward falls) was checked using the same goniometer. Participants were told that the tether will be released unexpectedly between 5 – 20 seconds, in order to induce a real-life fall that occurs unanticipatedly. Participants were instructed to fall in four different ways forward and backward. The order of the forward vs. backward falls was counterbalanced across participants. Forward falls included a natural fall (FNat), for which no specific instruction was provided other than no stepping, knee-first-fall (FKne), for which participants were instructed to fall on knees first before contact with other parts of the body, hand-first-fall (FHan), with corresponding instruction to fall on hands first before other parts of the body, and a twist fall (FTwt), in which participants were instructed to twist the body once released and fall on the side either left or right whichever the participants preferred. The four backward falls were similar. It consisted of a natural fall (BNat), butt-first-fall (BBut), hand-first-fall (BHan), and a twist fall (BTwt). For both forward and backward falls, the natural falls always started first, and the order of the three other types of falls was randomized across all participants to minimize possible order effects. In addition, the natural falls were repeated four times, and the other three falls were repeated three times. In the case when participants did not fall in the way they were instructed, that special trial was repeated until the required number of falls were completed in each condition. The pre-intervention session lasted 1.5 – 2 hours.

During the post-intervention fall mechanics testing session, we repeated the same procedure of the falls from standing for the C group, just like we did for the pre-intervention session. For the SC group, however, participants performed the natural falls first in one direction of falling and then the forward fall technique (FFT) falls or backward fall technique (BFT) falls that they learned during the training, rather than the three falls they performed in the prior session. Again, the forward or backward direction order was counterbalanced. In the case when participants used steps for the natural falls, more natural fall trials were repeated until a total of four “good” trials were completed. For FFT and BFT, since there were no specific standards to determine if participants properly used the SCFT, only four trials were conducted for each direction. The post-intervention session lasted approximately 1 – 1.5 hours.

2.4.2. *SCFT Training Program*

Participants who were assigned to the SC group were asked to attend four SCFT training sessions over two weeks. Professor Cara Rawlings, a certified SCFT training instructor, led the training sessions with a group of six or seven participants at a time. Each training session lasted approximately an hour. The fall technique training involved the instructor first demonstrating a falling technique while talking through important strategies. According to Professor Rawlings, these strategies included falling "away" from their body rather than straight down, while spreading out their body and intentionally contacting the floor with multiple "meaty" portions of the body (not bony parts) in a sequential manner to reduce impact forces on the body. Participants were encouraged to imitate and repeat the falling technique demonstrated by the instructor. Verbal feedback from the instructor was used to refine the technique. Attendance of each participant was recorded to ensure every participant in the SC group is trained with the fall technique. Participants were required to complete all four training sessions to be compliant with training.

2.4.3. *Expert Group Testing Session*

To explore how much improvements the SCFT training can show in terms of our dependent variables, we recruited six experts (20-44 years old, 2 males and 4 females), from the School of Performing Arts at Virginia Tech. Mean (SD) age, stature, and body mass of the 6 experts were 24.7 (9.5) years, 168.5 (8.7) cm, and 71.8 (7.3) kg, respectively. Five of them were students that have completed substantial training on the SCFT and received a Pass in the Society of American Fight Directors Skills Proficiency Test, and one of them was an expert with 19 years of experience in the SCFT who has regularly practiced and led the SCFT training sessions. They were asked to come for one fall mechanics testing session, which lasted about an hour. During the session, their basic anthropometric measures (i.e., height and weight) were recorded, and they completed the same falls that the participants in the SC group completed during their post-intervention testing session. For the expert group, only kinetic data were recorded during the fall trials.

2.5. Data Collection

During all fall mechanics testing sessions, reflective markers were placed at anatomical landmarks based on a modified Helen Hayes marker set (Allin, Wu, Nussbaum, & Madigan, 2016; Kadaba, Ramakrishnan, & Wootten, 1990), as shown in Figure 2. Positions of these reflective markers were captured by a 12-camera motion capture system (Qualisys, Goteborg, Sweden) at a sampling rate of 100 Hz and used to compute fall kinematics. Ground reaction forces upon impact of falls from standing were sampled at 2000 Hz using a 6-degree of freedom force platforms (AMTI OR6-7-1000, AMTI BP6001200, Watertown, MA). Three force platforms were placed under the wooden platform and a thick mat, as described earlier. Recordings from the motion capture system and the force platform were synchronized. Baseline data when participants stood over the fall platforms was recorded, for comparison with impact forces after falls. In addition, static motion capture calibration was performed when participants were attached with all reflective markers. The pre- and post-intervention fall mechanics testing sessions were recorded in videos to evaluate any additional effects of the SCFT training. These videos were also used when making final decisions on whether participants fell in the way that was instructed.

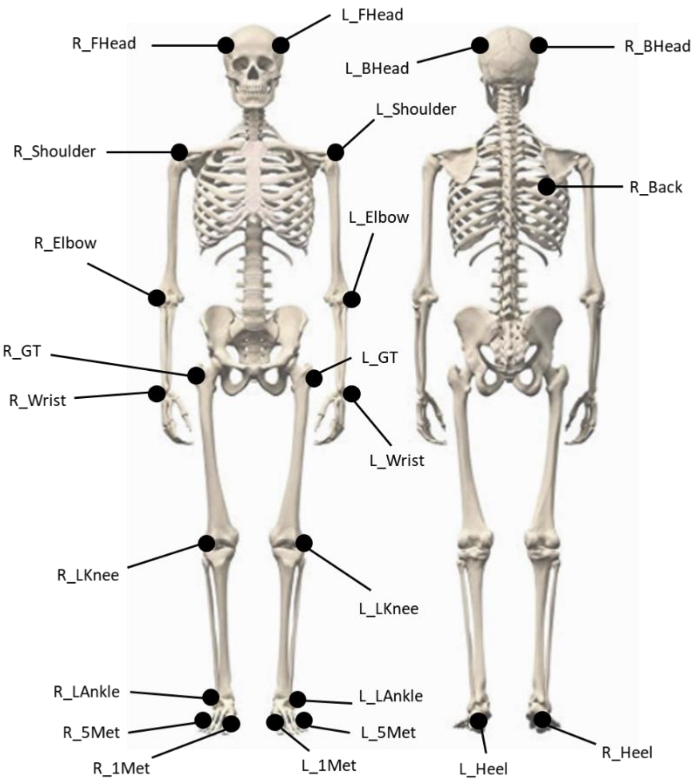

Figure 2. Modified Helen Hayes marker set (Allin et al., 2016; Kadaba et al., 1990). R_FHead = right front head; L_FHead = left front head; R_BHead = right back head; L_BHead = left back head; R_Shoulder = right acromion; L_Shoulder = left acromion; R_Back = right back (scapula); R_Elbow = right elbow; L_Elbow = left elbow; R_Wrist = right wrist; L_Wrist = left wrist; R_GT = right greater trochanter; L_GT = left greater trochanter; R_LKnee = right lateral knee; L_LKnee = left lateral knee; R_LAnkle = right lateral malleolus; L_LAnkle = left lateral malleolus; R_1Met = right 1st metatarsal head; L_1Met = left 1st metatarsal head; R_5Met = right 5th metatarsal head; L_5Met = left 5th metatarsal head; R_Heel = right calcaneus; L_Heel = left calcaneus.

2.6. Data Analysis

Seven dependent variables were calculated to quantify fall impact severity: impact force, fall duration, impact time, impulse, total excursion of COP, 95% confidence ellipse area of COP, and rectangle area of COP. All dependent variables were obtained using custom-written code in MATLAB® (The MathWorks, Natick, MA, USA). Prior to the computations, reflective marker data was filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 6 Hz. Force data was filtered using a fourth-order Butterworth low-pass filter with a cutoff frequency of 200 Hz.

Impact force was directly measured from the three force platforms. The sum of all forces in the vertical direction was used to compute the impact force. In addition, impact forces were normalized to the participants' body weight (Weerdesteyn et al., 2008) for appropriate comparisons across participants. Fall duration was defined as the interval from when participants were released from the tether (determined as the instant when the resultant velocity of either the left or right acromion marker exceeded 0.1 m/s) to when the impact force exceeded 50 N. Impact time was defined to be the time between when the impact force exceeded 50 N to when the impact force reached the peak. Impulse was calculated as the area under the impact force curve during the impact time.

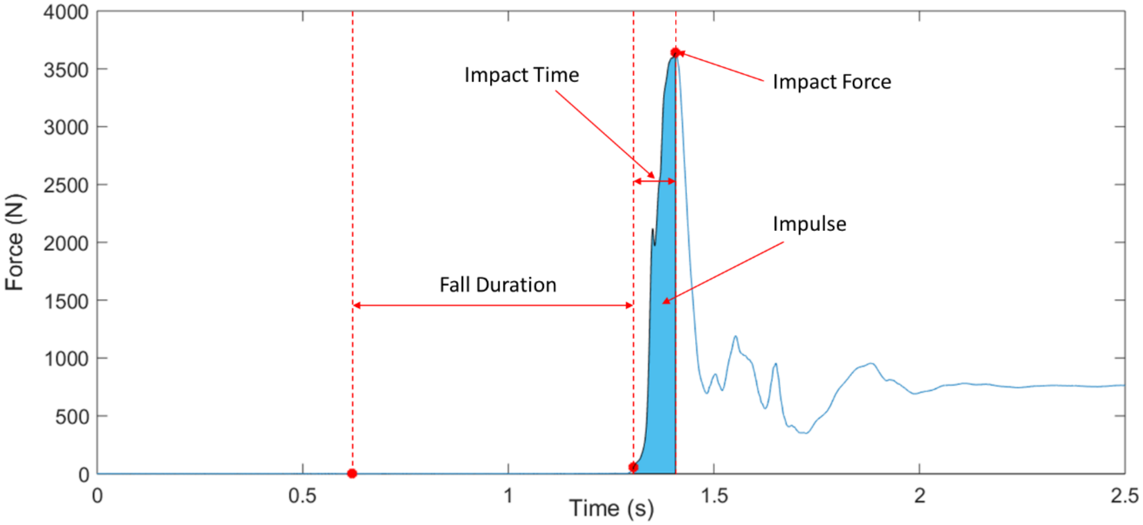

Figure 3. Illustration of impact-force-based parameters (i.e., impact force, fall duration, impact time, and impulse).

Other than these parameters used to measure the severity of falls, our study explored other parameters, which have been used to quantify postural sway of quiet standing in other studies, to quantify the area of impact of falling. Several measures have been identified by past studies to quantify postural steadiness of quiet standing (Hufschmidt, Dichgans, Mauritz, & Hufschmidt, 1980). They are COP based parameters, such as COP displacement in ML and AP directions, that are used to characterize the steadiness of postural control or balance (Prieto et al., 1996). However, in our study, these measures were used to estimate the area of impact of falling. Impact area was defined as the area of the impact over which participants landed on the falling mat. First, the overall COP or the weighted average COP of all three COP values in both ML and AP directions from the three different force platforms was calculated, using the equation (1) shown below.

$$\text{Overall COP}_{\text{x or y}} \ (\text{or weighted average COP}_{\text{x or y}}) = \frac{COP_{x\ or\ y,FP1} * F_{z,FP1} + COP_{x\ or\ y,FP2} * F_{z,FP2} + COP_{x\ or\ y,FP3} * F_{z,FP3}}{F_{z,FP1} + F_{z,FP2} + F_{z,FP3}}, \quad (1)$$

where COP_x is the COP in ML direction, COP_y is the COP in AP direction, and F_z is the vertical ground reaction force measured from each o the three force platforms FP1, FP2, and FP3

Then, the three different methods were used to estimate the impact area, using the three equations: (2) total excursion, or the total distance that the overall COP has travelled during the impact time, (3) 95% confidence ellipse area of the overall COP during the impact time, and (4) rectangle area of the overall COP during the impact time.

$$\text{Total Excursion} = \sum_{n=1}^{N-1} \sqrt{(COP_x[n+1] - COP_x[n])^2 + \left(COP_y[n+1] - COP_y[n]\right)^2}\,, \quad (2)$$

where N is the total number of COP samples, n is the nth COP sample, $COP_x[n]$ is the nth COP in ML direction, and $COP_y[n]$ the nth COP in AP direction

$$95\%\ Confidence\ Ellipse\ Area = \pi ab = 6\pi\sqrt{\left[s_x^2 s_y^2 - s_{x,y}^2\right]}, \quad (3)$$

where s_x is the standard deviation of COP time series in ML direction, s_y is the standard deviation of COP time series in AP direction, and $s_{x,y}$ is the covariance of COP time series in both ML and AP directions

$$Rectangle\ Area = [max(COP_x) - min(COP_x)] * [max\left(COP_y\right) - min(COP_y)], \quad (4)$$

where $max(COP_x)$ or $max(COP_y)$ is the maximum COP in ML or AP direction among COP time series, and $min(COP_x)$ or $min(COP_y)$ is the minimum COP in ML or AP direction among COP time series

When calculating the COP displacements from each of the three force platforms, a new threshold were defined, in order to exclude the instants when other unnecessary forces were applied on the mat (i.e., the metal ring attached at the end of the tether hitting the mat) or when the mat bounced up due to its elasticity, right after the impact occurred. For each force platform, the COP displacements were computed when the vertical force exceeded 150 N, during the impact time that was defined earlier. The time frames when the vertical force was 150N or below, the COP values were defined to be 0. Then, these COP values were used to compute the overall COP, or weighted average COP. When calculating the overall COP, at least one of the three force platforms were required to have the vertical force higher than 150 N. The time frames when none of the three force platforms showed the vertical force higher than 150 N, the overall COP was defined to be not-a-number because we did not want to include the overall COP when it is 0, as it will affect the COP-based parameters. When computing the three COP-based parameters, the trials that showed minimum vertical impact force of -50 N or below from at least one of the three force platforms were excluded, because the vertical forces being -50 N or below (i.e., the instants when the mat was pulled up in the air during impact) affected the final impact area values.

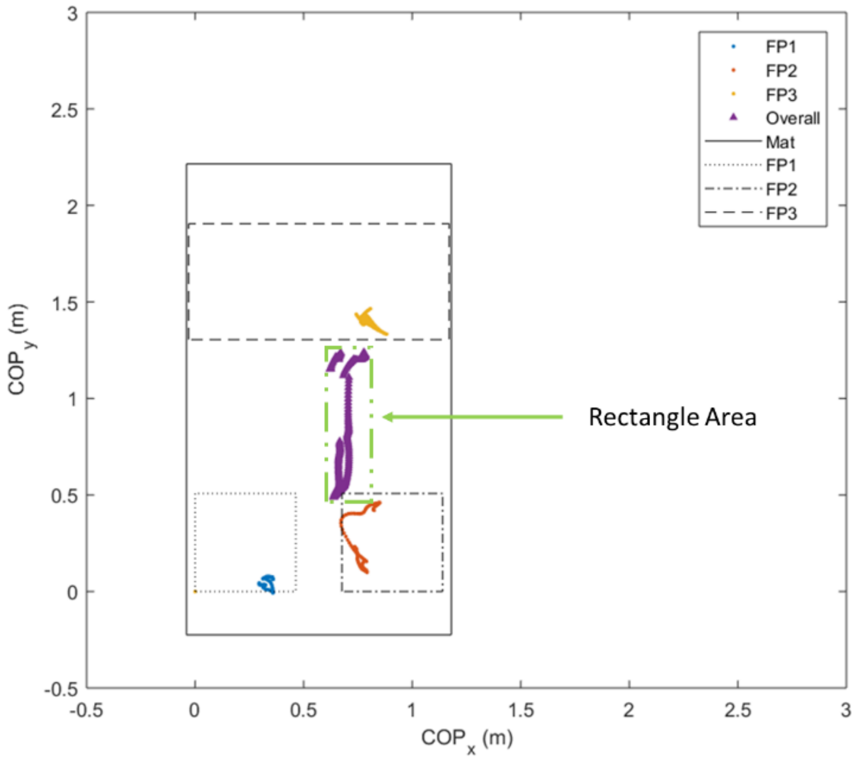

Figure 4. Example COP trace plot, as a resultant of the measures from the three force platforms underneath the falling mat, recorded during a forward naturalistic fall performed by a participant in the pre-intervention session.

2.7. Statistical Analysis

Because some of our dependent variables were not normally distributed, the non-parametric Mann-Whitney U test was used for all of our dependent variables, to maintain consistency in the statistical analysis. The effect of Group (i.e., SC or C) on pre-intervention measures of impact force, fall duration, impact time, impulse, total excursion, 95% confidence ellipse area, and rectangle area were first investigated. Following this, the effect of Group on change in each of these variables from pre-intervention to post-intervention, were investigated. Separate tests were performed for fall direction (i.e., forward or backward falls). In addition, non-parametric contrasts were computed using group medians to quantify the effect size of group, according to the equation used in the study by Srinivasan, Sinden, Mathiassen, and Côté (2016), as shown in equation (5) below.

(5)

$$\text{Contrast} = \frac{\text{MAD}_{\text{bg}}^2}{MAD_{bg}^2 + MAD_{wg}^2},$$

where $\text{MAD}_{\text{bg}}{}^2$ is the average of the median squared deviation of a group median and overall median values (between-group), and $\text{MAD}_{\text{wg}}{}^2$ is the median of all median squared deviations of each participant mean and a group median (within-group)

The contrast values were used to measure the likelihood that individuals from one group will always differ than the individuals in the other group. The values are on a scale from 0 to 1, with 0 being the least likelihood and 1 being the highest likelihood that there is a genuine group difference. The statistical analysis was performed using JMP 14 (SAS Institute, Inc., Cary, NC) with a significance level of $\alpha \leq 0.05$.

3. RESULTS

A total of 1318 fall trials was collected from the 26 participants and 6 experts during this study. During data processing, 3 trials were excluded from the impact-force-based measures because the participants did either not fall in the instructed way, or data was corrupted while processing. During computation of the COP-based measures, 16% of trials were excluded due to the force thresholds described in the methods section not having been met.

Figure 5 shows the group medians of impact force, fall duration, impact time, impulse, COP total excursion and impact area of Nat vs. FT falls among the C and SC groups during pre and post-intervention, and the FT falls performed by the expert group. Figure 6 similarly shows the medians and group distributions of the same dependent measures of Nat vs. Nat falls at pre- and post-intervention in the C and SC groups. From Figures 5 and 6, it can be seen that impact force was roughly 3-5% body weight and reduced during the FT falls performed by the SC group. Fall duration was in the range of 0.5 – 1 s and showed the most change for the backward falls performed by the SC group, from pre- to post-intervention (Figure 5, panel 2). While impact time was in the range of 0.1-0.2 s, impulse in the range of 0.2-0.4 Ns / N, and COP total excursion in the range of 0.5 – 3 m at pre-intervention, following the SCFT training, these variables increased dramatically, by 300-400%, in the SC group, while COP impact area doubled, correspondingly. The values of these dependent measures from the expert group are also shown in Figures 5 and 6, for descriptive summary and comparison purposes.

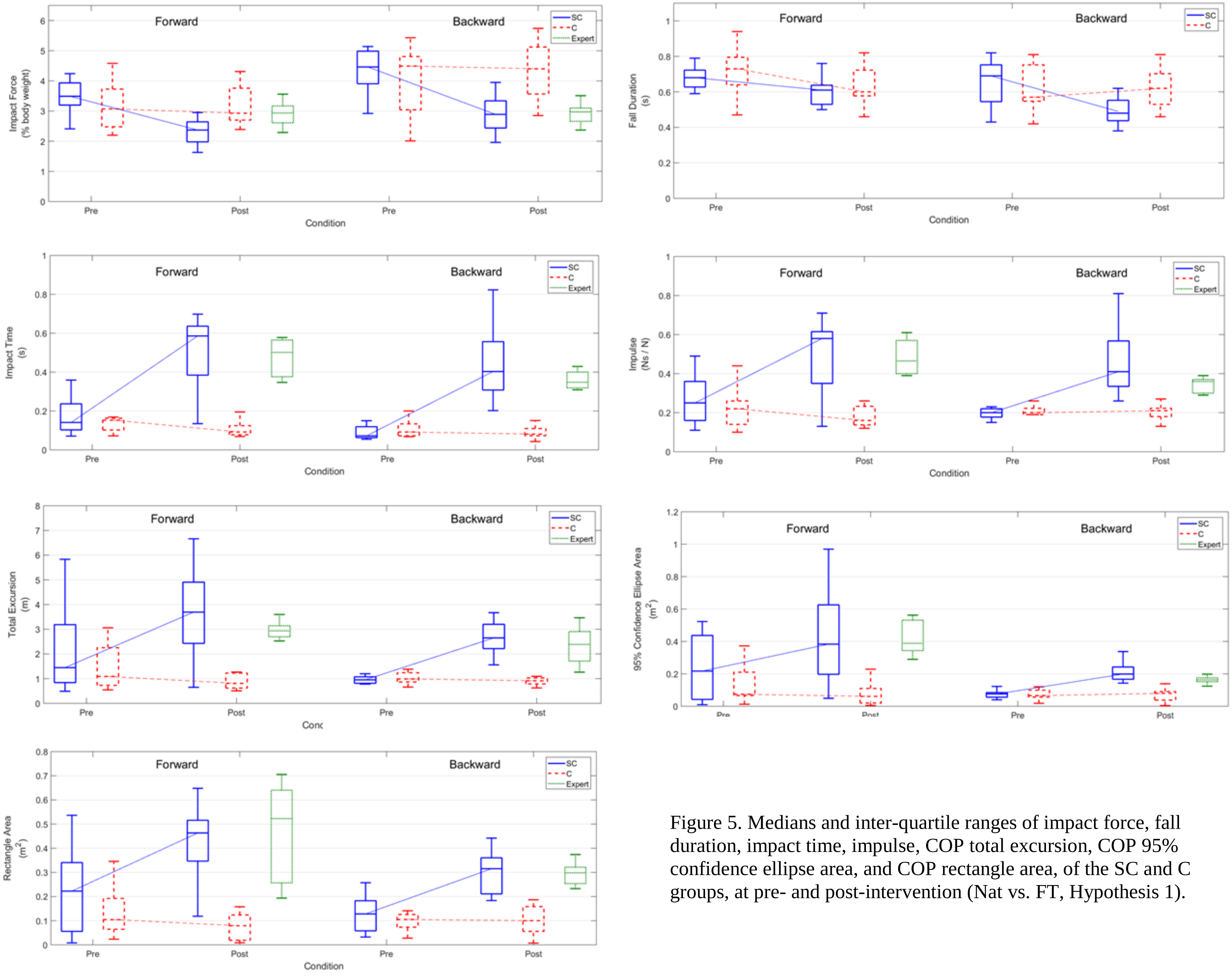

Figure 5. Medians and inter-quartile ranges of impact force, fall duration, impact time, impulse, COP total excursion, COP 95% confidence ellipse area, and COP rectangle area, of the SC and C groups, at pre- and post-intervention (Nat vs. FT, Hypothesis 1).

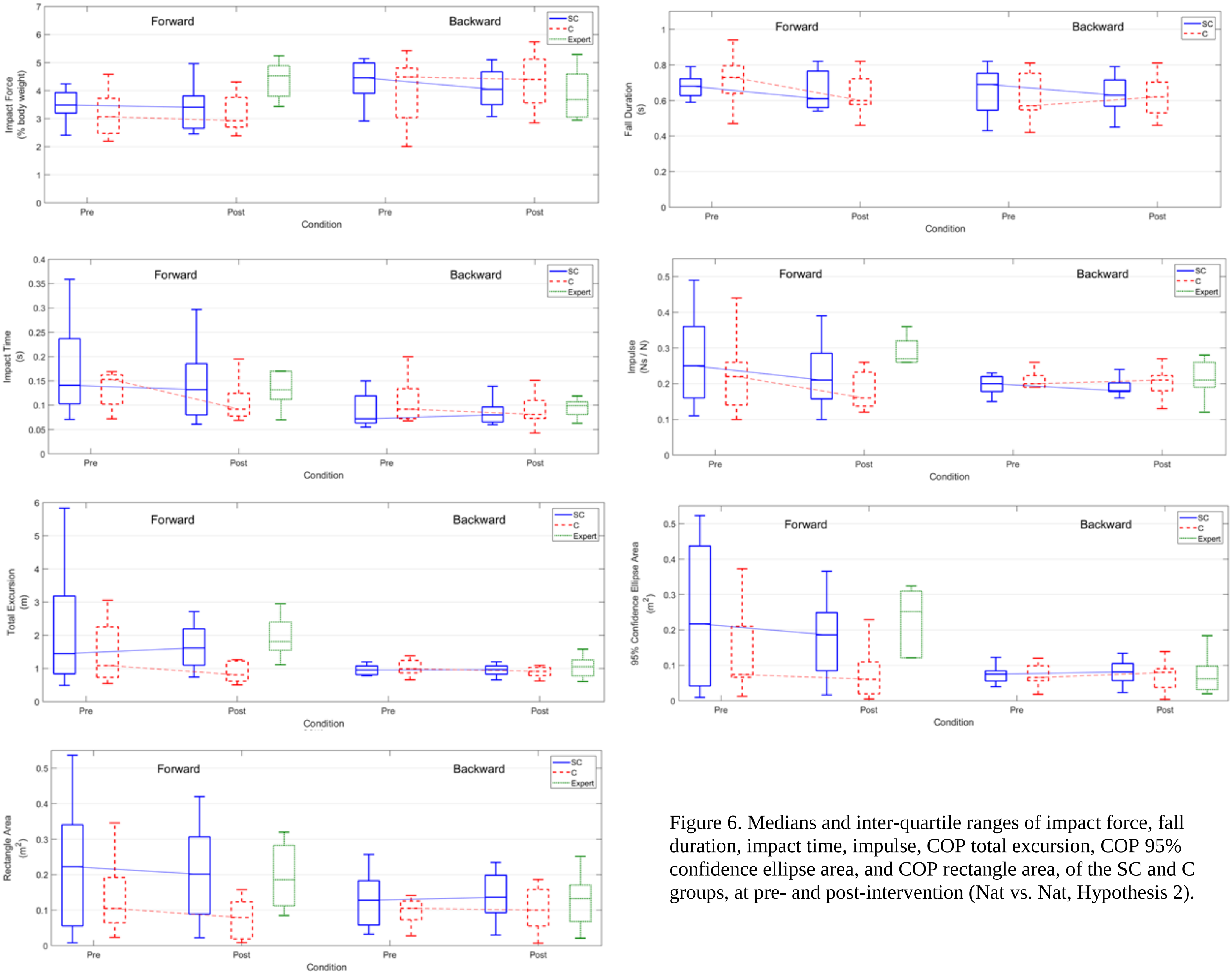

Figure 6. Medians and inter-quartile ranges of impact force, fall duration, impact time, impulse, COP total excursion, COP 95% confidence ellipse area, and COP rectangle area, of the SC and C groups, at pre- and post-intervention (Nat vs. Nat, Hypothesis 2).

The results of the Mann-Whitney U test for all variables, corresponding to both hypotheses (i.e., Nat vs. FT and Nat vs. Nat), are shown in Table 1.

Table 1. Summary of the descriptive statistics, *p*-values, and contrasts for the dependent variables, by Direction and Group. Statistically significant effects are in bold ($p < 0.05$).

Dependent Variable	Group	Pre-Intervention				Change (SC - Nat vs. FT)				Change (SC - Nat vs. Nat)			
		Median	IQR	*p*	Contrast	Median	IQR	*p*	Contrast	Median	IQR	*p*	Contrast
Impact Force (% body weight)	F: SC	3.49	0.80	0.293	0.24	-1.13	0.88	**0.002***	**0.66**	-0.20	0.79	0.682	0.11
	F: C	3.07	1.31			0.12	1.28			0.12	1.28		
	B: SC	4.46	1.14	0.644	0.00	-1.65	1.20	**<0.001***	**0.85**	-0.04	1.14	0.106	0.12
	B: C	4.49	1.87			0.21	1.27			0.21	1.27		
Fall Duration (s)	F: SC	0.68	0.12	0.520	0.14	-0.07	0.09	0.680	0.01	-0.04	0.11	0.269	0.05
	F: C	0.73	0.16			-0.06	0.12			-0.06	0.12		
	B: SC	0.69	0.215	0.625	0.50	-0.15	0.14	**<0.001***	**0.71**	-0.02	0.10	0.472	0.14
	B: C	0.57	0.21			0.02	0.12			0.02	0.12		
Impact Time (s)	F: SC	0.141	0.140	0.644	0.02	0.256	0.304	**<0.001***	**0.86**	-0.010	0.176	0.939	0.00
	F: C	0.153	0.067			-0.012	0.098			-0.012	0.098		
	B: SC	0.072	0.068	0.248	0.20	0.325	0.310	**<0.001***	**0.94**	-0.007	0.040	0.720	0.18
	B: C	0.092	0.065			0.001	0.034			0.001	0.034		
Impulse (Ns / N)	F: SC	0.25	0.21	0.227	0.04	0.18	0.41	**<0.001***	**0.67**	-0.01	0.24	0.980	0.06
	F: C	0.22	0.13			-0.04	0.13			-0.04	0.13		
	B: SC	0.20	0.05	0.366	0.00	0.21	0.32	**<0.001***	**0.82**	-0.01	0.05	0.758	0.04
	B: C	0.20	0.04			0.00	0.08			0.00	0.08		
Total Excursion (m)	F: SC	1.446	2.397	0.473	0.08	2.108	2.924	**0.005***	**0.79**	0.113	2.612	0.532	0.06
	F: C	1.089	1.585			-0.191	1.355			-0.191	1.355		
	B: SC	0.952	0.284	0.457	0.02	1.711	1.416	**<0.001***	**0.96**	-0.008	0.138	0.602	0.05
	B: C	0.987	0.427			-0.081	0.528			-0.081	0.528		
95% Confidence Ellipse Area (m^2)	F: SC	0.2171	0.4001	0.758	0.24	0.3270	0.4352	**0.012***	**0.82**	-0.0117	0.4636	0.935	0.06
	F: C	0.0741	0.1502			-0.0505	0.2083			-0.0505	0.2083		
	B: SC	0.0754	0.0350	0.918	0.09	0.1281	0.1146	**<0.001***	**0.77**	0.0067	0.0465	0.728	0.01
	B: C	0.0657	0.0471			0.0108	0.0514			0.0108	0.0514		
Rectangle Area (m^2)	F: SC	0.2225	0.3098	0.505	0.36	0.2369	0.2658	**0.002***	**0.64**	-0.0158	0.3232	0.724	0.05
	F: C	0.1046	0.1444			-0.0479	0.1798			-0.0479	0.1798		
	B: SC	0.1280	0.1268	0.473	0.12	0.1891	0.1000	**0.002***	**0.81**	0.0044	0.0717	0.817	0.11
	B: C	0.1051	0.0560			-0.0157	0.1054			-0.0157	0.1054		

At baseline (i.e., pre-intervention), there were no significant group differences in any of the dependent measures. In accordance with our hypothesis 1 (i.e., Nat vs. FT for SC group, and Nat vs. Nat for C group), all dependent variables showed significant group differences in change from pre- to post-intervention, except the forward fall duration. In addition, the effect sizes were large (i.e., median contrast values higher than 0.6). The change in naturalistic fall measures from pre to post intervention (i.e., Hypothesis 2) was not significantly different between the groups.

4. DISCUSSION

4.1. Aim and Hypotheses

The purpose of the study was to investigate the effect of the SCFT as a possible intervention to reduce fall-related injuries, which are the top leading cause of fatal and non-fatal injuries in the United States, especially among older adults. As an initial step to develop an effective intervention, our study aimed to test the effects of the SCFT on impact forces of fall from standing with the groups of healthy young adults.

Our Hypothesis 1 that the impact forces of falls from standing will reduce when participants used the SCFT after training, as compared to when the participants fell naturally without any training, was confirmed. For both directions of falls, the change in impact forces among the SC group who used the SCFT was significantly different than the change of impact forces from the C group who did not receive training or was instructed to use the SCFT. As a result, in terms of % median (IQR) change, the post impact force scores in the SC group showed -32% (0%) and -35% (-17%) changes, for forward and backward falls respectively, while the C group showed only -5% (-16%) and -2% (-8%) changes. This result was similar to other studies by B. E. Groen et al. (2010); B. E. Groen, Weerdesteyn, and Duysens (2007); Weerdesteyn et al. (2008) that used a MAFT to reduce hip impact force from sideways falls from the kneeling position. These studies showed significant reduction in hip impact forces when the MAFT was used, compared to the control group who did not use the MAFT. Regarding fall duration, the change of fall duration between the two groups were significantly different for backward falls in that the post fall duration scores in the SC group exhibited -30% (-44%) change, while the C group exhibited only 9% (-7%) change. This finding was partially consistent with the finding from a previous study by B. E. Groen et al. (2010) that used a MAFT to prevent hip injuries and reported non-significant differences in fall duration for sideways falls. This difference could be explained by the different methods each fall technique uses. While the MAFT focuses more on having larger impact area of the body, the SCFT requires to step immediately after the fall is initiated and roll subsequently, which may in turn result in significantly different fall duration. The impact time and impulse showed the same trends for both directions. The change of impact time and impulse scores were significantly different between the two groups that the SC group showed 316% (84%) and 460% (353%) changes in impact time, as well as 132% (29%) and 105% (489%) changes in impulse, for forward and backward falls respectively, while the C group showed -40% (-17%) and -12% (-37%) changes in impact time, as well as -27% (-23%) and 5% (29%) changes in impulse. Impact time may have increased due to the immediate steps or the starting instant of impact time, which are required for the SCFT, and subsequent rolling movements, which may have increased the duration from the initial impact to the peak impact. The impulse was directly influenced by this change because it was calculated using the impact time and the impact force during the impact time. The higher impulse when the SCFT was used tells that the change of momentum was not as rapid as when natural reaction was used, which indicates that smaller impact force was applied to the body during the longer time interval. This finding may explain why the SCFT could be an effective intervention to mitigate the risk of fall-related injuries. The three COP-based impact area parameters showed the same pattern that the change between conditions were significantly different in both groups. Consequentially, all the post-intervention COP based measures were higher in the SC group than C group, for both directions of falls. The SC group showed 155% (15%) and 178% (351%), 77% (19%) and 163% (199%), and 108% (-35%) and 146% (27%) changes in total excursion, 95% confidence ellipse area, and rectangle area, respectively. On the other hands the C group showed -26% (-60%) and -

8% (-36%), -18% (-27%) and 22% (23%), and -24% (-19%) and -5% (92%) changes, respectively. These changes were consistent with the principles of SCFT that the technique induces rolling movement and thus distributes impact forces into larger or wider area, which could help reduce the risk of fall-related injuries.

Our Hypothesis 2, that the impact forces of falls from standing will reduce when the participants fall naturally after SCFT training, as compared to when the participants fall naturally without the SCFT training, was not confirmed. None of the dependent variables showed significant changes when the two groups were compared for naturalistic falls. However, the expert group was also quite similar with the post-intervention measures from both groups. This finding could be because all participants were restricted from using steps for the natural falls, and that may have caused participants to fall similarly and thus resulted in similar measures. Stepping was restrained to make sure participants performed complete falls; however, if stepping had not been restrained, the way that the experts fell naturally may have looked like their SCFT falls since the experts were very used to implement the SCFT for falls in any situations. In addition, it might have been easier to determine if the dosage of training used in this study is enough for healthy young adults to perform the SCFT when falling naturally.

Lastly, the six different falling strategies (i.e., FKne, FHan, FTwt, BBut, BHan, and BTwt) were tested to provide a more comprehensive basis of different types of falls. We were able to see that the scores were similar with the scores from when the participants fell naturally. This might be because that the natural reactions people used were very similar with one or more strategies of these specific falls. In addition, this finding may provide some explanations that the SCFT falls could better help reduce the risk of fall-related injuries than these strategies of falling could help, as the effect size of the SCFT in impact force was very strong when the SCFT was compared with natural falls.

4.2. Limitations

Our study had several limitations. First, since there were no similar studies done in the past, our sample size was determined arbitrarily. The small sample size might have led to the non-normal residual distributions of our dependent variables. With larger sample size, we may see normal distributions of the dependent variables and thus be able to consider more complex models with other confounding factors included as potential covariates, such as stature, body weight, and gender. Second, although our lab setup or the fall platform was created to resemble the falls that could happen in our daily life, the laboratory environment and equipment may have affected the natural reactions that the participants used for the fall trials. With the thick soft mat in front of or behind them, they may have felt comfortable falling, with less fear of being injured. Third, the innate individual differences (i.e., motor ability) between participants could have affected the results for our study with limited amount of training. The dosage of the training required for most people to effectively use the SCFT will need to be further investigated. Despite these limitations, our study was designed to induce falls that closely resemble falls in real-life situations, and tested groups of participants who had no prior experience in any fall technique training. Our findings could help develop SCFT as one of the possible interventions to reduce the number of fall-related injuries in future.

4.3. Conclusion

Our findings showed that the principles of SCFT helped reduce forces upon impact of falls from standing and thus could help decrease possibility of fall-related injuries, such as fractures, among healthy young adults. Future work should focus on age-related fall risk factors as well as duration of training required to yield significant reduction on impact forces of real-life falls, by investigating the effects of the SCFT training among older adults. Falls from different situations (i.e., trips and slips while walking or stepping up/down) should also be tested with the SCFT to determine whether the technique can be implemented and/or reduce the risk of fall-related injuries in various situations.

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APPEDNIX

Different Ways to Fall

As our secondary outcomes of interest, falls using different strategies were explored in terms of the seven dependent variables. Although no formal statistical analysis was performed, the descriptive statistics values of these falls were still computed and shown in Figures 7, 8, 9, 10, 11, 12, and 13, for visual comparisons with the descriptive statistical measures from the natural falls and/or the SCFT falls.

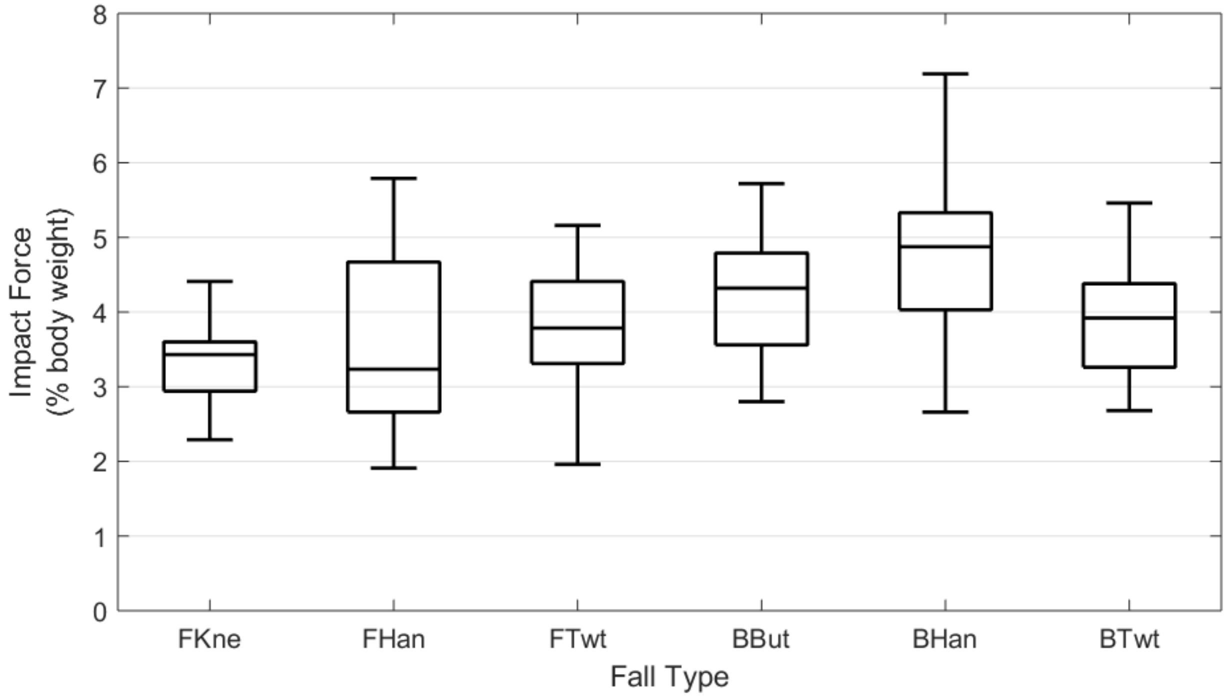

Figure 7. Impact force scores when the different instructions to fall were given.

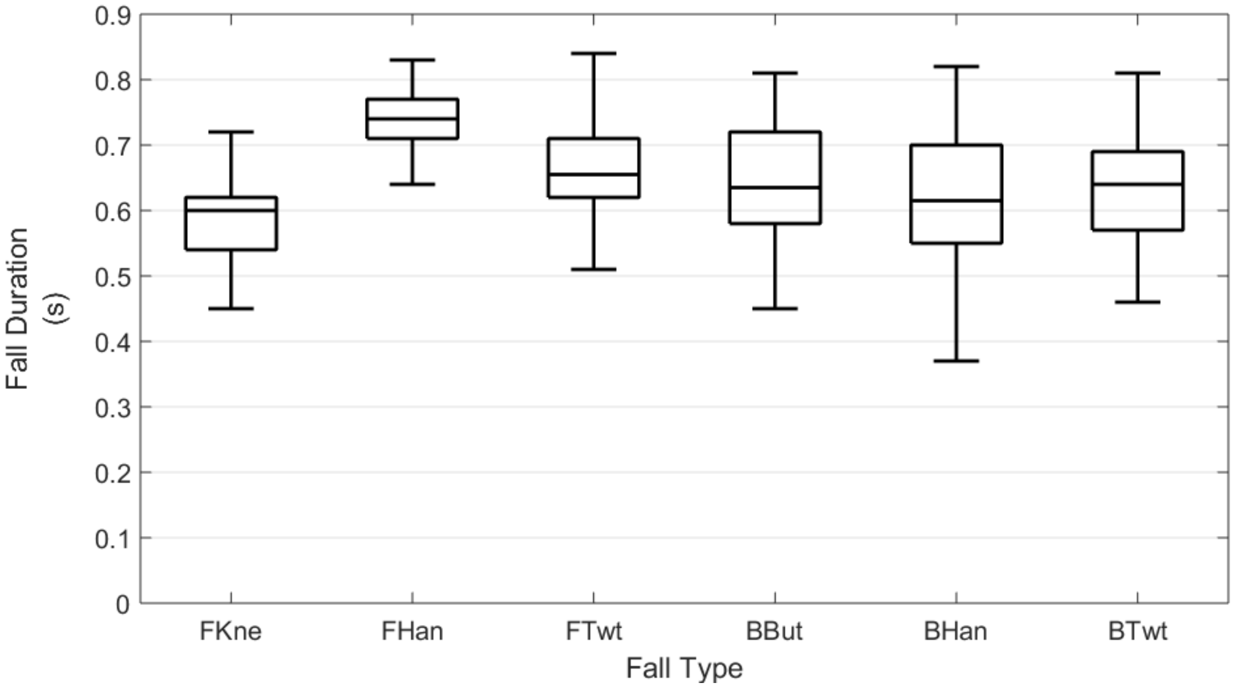

Figure 8. Fall duration scores when the different instructions to fall were given.

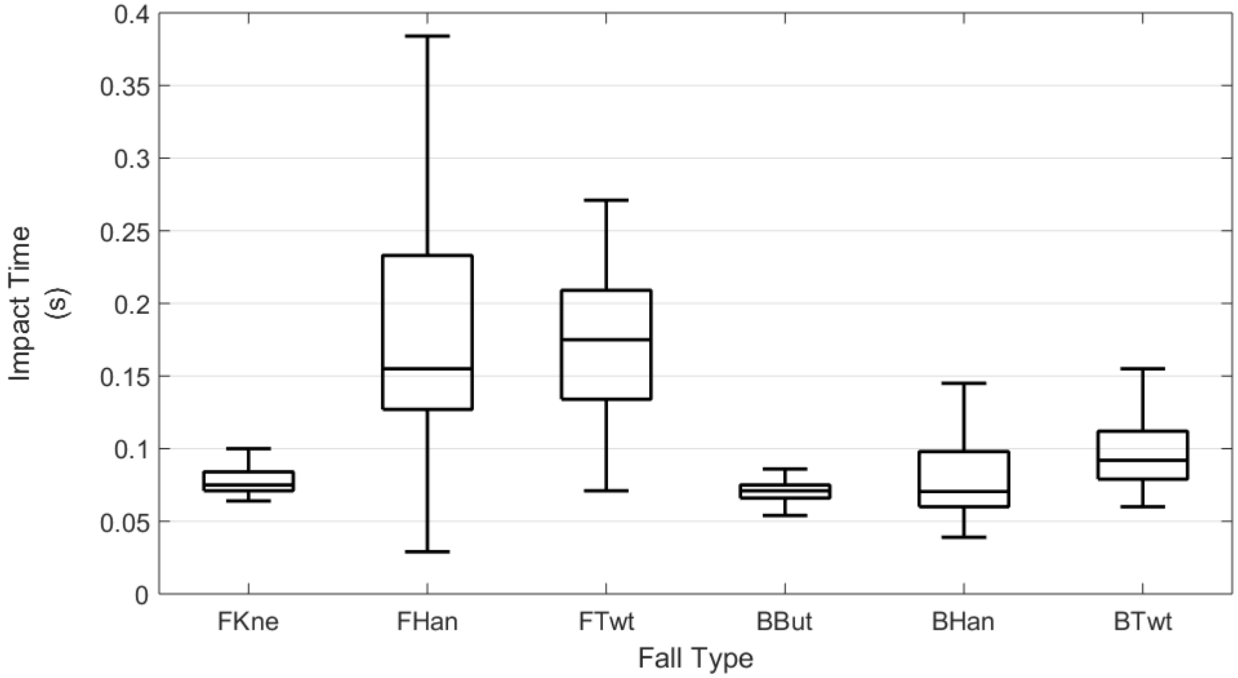

Figure 9. Impact time scores when the different instructions to fall were given.

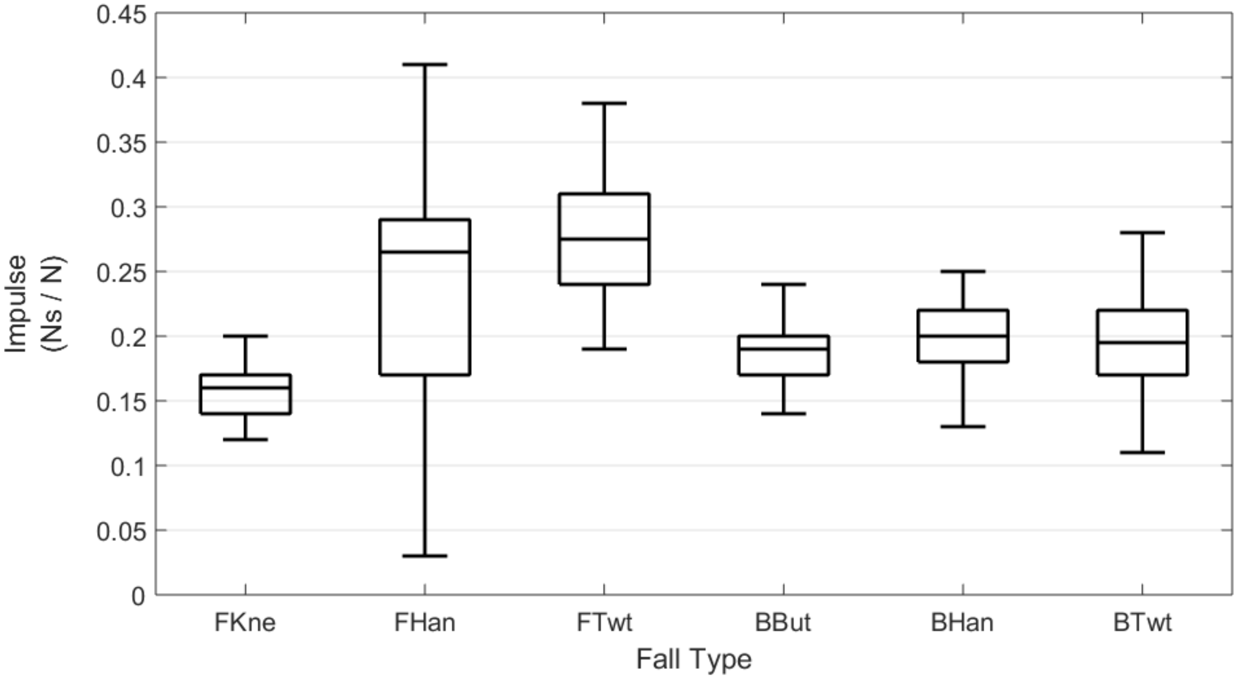

Figure 10. Impulse scores when the different instructions to fall were given.

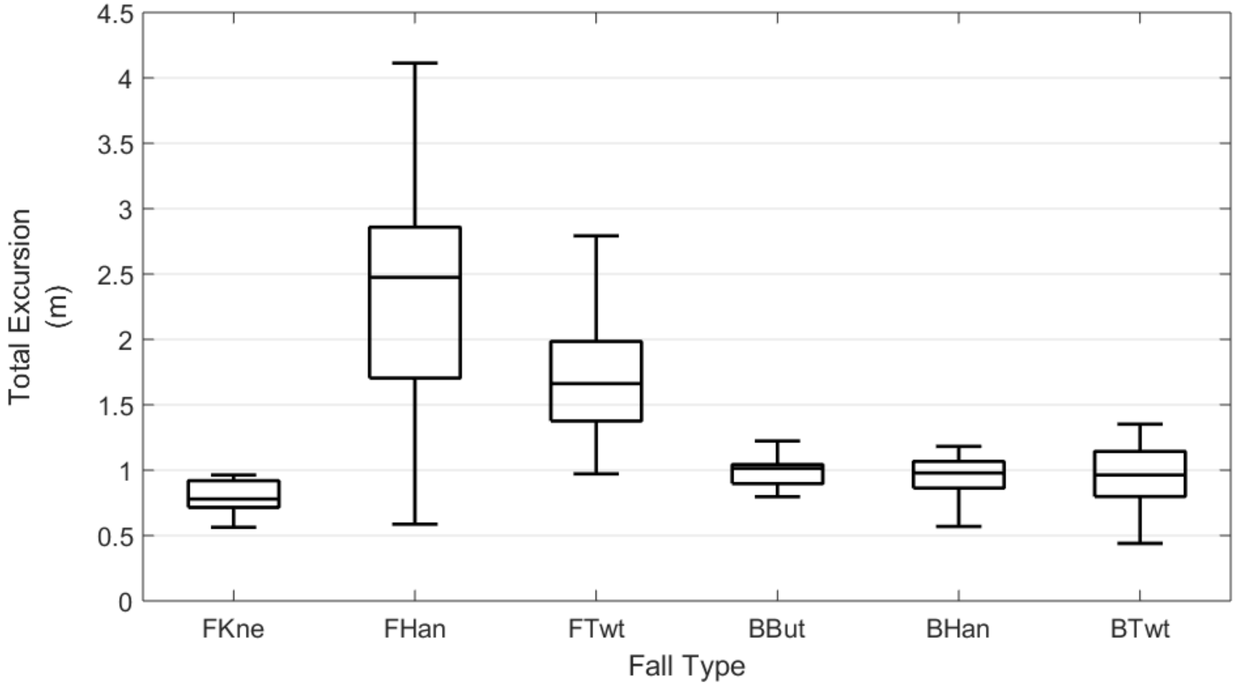

Figure 11. Total excursion scores when the different instructions to fall were given.

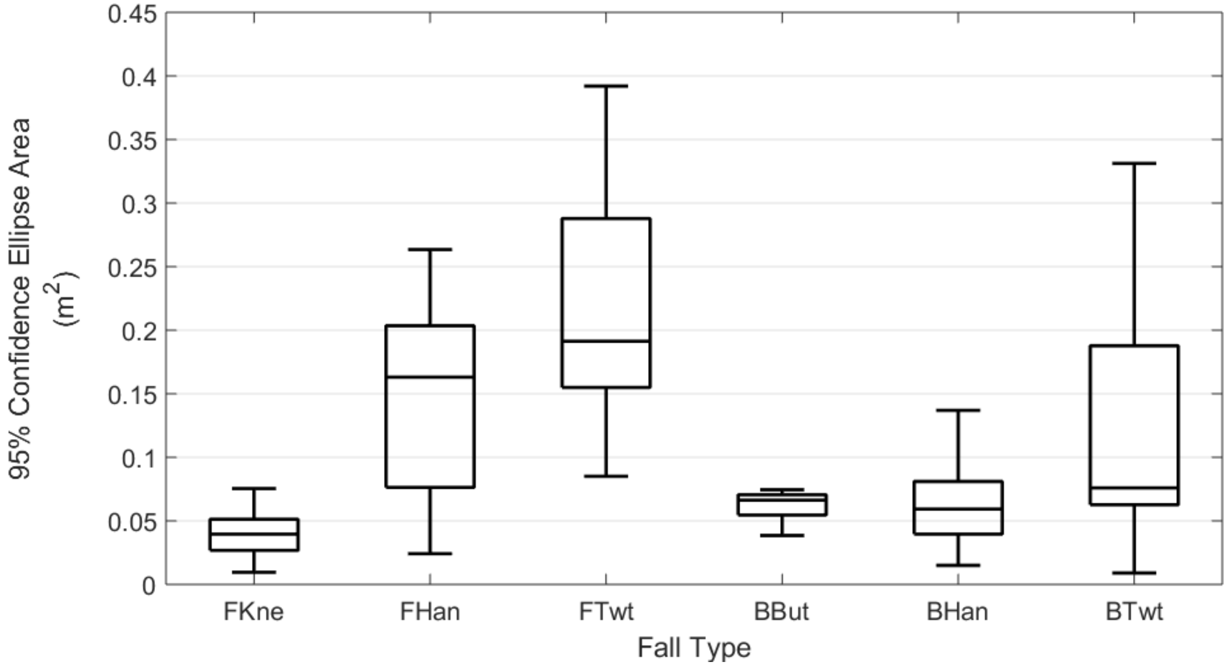

Figure 12. 95% confidence ellipse area scores when the different instructions to fall were given.

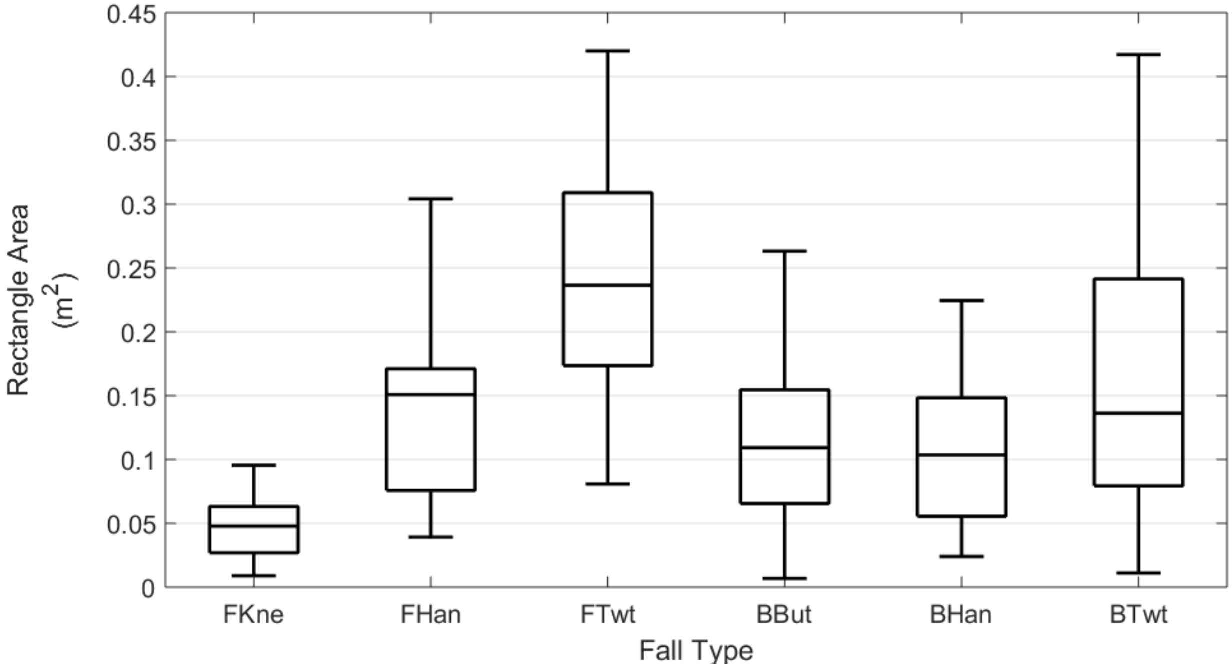

Figure 13. Rectangle area scores when the different instructions to fall were given.