Assessment of Arm Motions with Fall Direction in Human Subjects

By

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Abstract

Falls are a common and serious problem among older adults. This study examined the role of the direction of fall on the movement of arms. The specific aims of the study were to characterize the arm motion in response to a fall perturbation and to determine if there was any correlation between the side of fall and the motion of either arm. Electromagnetic motion sensors were placed on left/right upper arm, left/right forearm, thorax (T1) and sacrum (between S1 & S2) on 12 subjects. Controlled falls occurred in four directions: anterior, posterior, and medial-lateral directions. The assessment of average arm motion patterns displayed different characteristics in different directions. Analysis of variance showed that peak shoulder rotation had a significant interaction between the left/right lateral fall directions and arm side measured (side*direction $p < 0.05$). In case of shoulder abduction, left and right lateral fall directions' interactions were significant for the interaction of side*direction ($p<0.05$). For elbow flexion, the interaction of side*direction ($p=0.096$) did follow a trend though not significant in the medial lateral directions. It was hypothesized that left/right arm response in lateral falls would correspond to the fall direction and the pattern would reverse for falls in the opposite direction. It was further hypothesized that in anterior/posterior falls; differences in arm motions would exist and be symmetric across both arms.

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I want to thank my family and friends for their immense support and words of encouragement during tough times. I would also like to express my love to my dogs Chaaya and Diya who let me work at peace even if it meant shorter walks.

This dissertation is dedicated to my parents, my brother and my husband who believed in me and love me the most.

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Chapter 1 Introduction

1.1 Significance

Falls are a common and significant problem for older adults in all parts of the world [1]. Injuries are the fifth leading cause of death in older adults and most of these fatal injuries are due to falls [2]. Falls are not only associated to mortality. Falls can result in a lack of confidence to ambulate safely, hospitalization and premature admission to nursing homes [3]. Serious injuries that occur during a fall include fractures, joint dislocation, head injury, joint injuries and other dislocations that can result in hospitalization and rehabilitation [4]. In a study conducted in Finland between 1970 and 2002, the humeral fractures due to falls and osteoporosis increased from 208 to 1120 [5]. Between the year 1970-2002, the incidence of humeral fractures (per 100,000) increased from 51 to 129 in women and 14 to 48 in men [5]. The mean patient age also increased from 73 to 78 years in women and 70 to 73 years in men [5]. If the same trend continued, the number of fractures in Finns would triple itself in the next three decades [5]. Similar trends have been observed in many industrialized nations including the US.

1.2 Background

Significance of Injuries

Falls are one of the most alarming causes of death in the present period. In the United States, falls in older adults were the second leading cause of death due to unintentional injuries in 1994

[2]. In the year 2000 there were 10300 fatal and 2.6 million non-fatal fall related injuries. The US health care system spent about $0.2 billion for fatal and $19 billion for non- fatal injuries as direct costs [6]. 35% of the non- fatal injuries were fractures; but they accounted for 61% of the costs [6]. Slips contributed about 85% of the falls and also to musculoskeletal injuries after slipping or tripping though it did not end with a fall [7]. Studies have found that the injuries from a fall can be influenced by the direction of the fall [8].

1.3 Importance of the study

There have been several studies that have been done in the past to examine the effects direction of fall and its impact on the hip, but less has been done to study the relationship between the direction of fall and arm motion [9-12]. Arm motion is important to study for a number of reasons including to assess the potential for arm related injuries (Colles' fractures), to assess the potential for the arm to shield other body parts (such as the hip or head) from injury, and to assess the potential for tracking arm motions as a means to assess falls remotely. In this project, the latter was particularly of interest in developing novel devices to assess falls that could operate solely via a wrist worn sensor. This study examined early arm motions during a fall event in younger adults. The specific aims were to characterize arm motion in response to a fall perturbation and to determine if there was any correlation between the direction of the fall and the movement of both the arms.

1.4 Methods of data analysis

Falls were artificially created using a tilting platform. Data were collected using electromagnetic sensors. These sensors collected motion data during falls in four different directions: anterior, posterior and medial-lateral fall directions. Arm motions that were assessed included 1) Left/Right shoulder rotation 2) Left/Right shoulder abduction and 3) Left/Right elbow flexion. Two methods were used to analyze the data: 1) assessment of average arm movement patterns and 2) analysis of variance (ANOVA). The assessment of average arm movement patterns helped to determine if there were any common pattern of motion for 1) Left/Right shoulder rotation 2) Left/Right shoulder abduction and 3) Left/Right elbow flexion for the four fall directions. The average of each of these arm movements in each direction with respect to time was determined by averaging four falls in each direction for each subject and then averaging patterns for each subject group (eyes open and eyes closed). The statistical analysis used mixed measures of ANOVA with repeated measures of arm side and fall direction and an additional independent non-repeated variable of visual input group (eyes open/eyes closed) to determine if there was any significant effect of the direction of fall, the side of the arm and the visual input on peak arm motion on the first second of the fall.

1.5 Thesis content

This work consists of six chapters. Chapter 1 is dedicated to introducing the area of study. Chapter 2 contains an extensive background search on the area of study. Chapter 3 consists of the method/protocol used in the study. Chapter 4 consists of the results obtained from the study. Chapter 5 discusses the results. Chapter 6 summarizes the study. Chapter 7 consists of the references used in the study. An appendix will contain information on the design and execution of the study.

Chapter 2 Background

2.1 Significance of falls

Falls are one of the most common and serious problems experienced by older adults in all parts of the world [1]. Studies have concluded that every year 30 % to 60% of the older adults over the age of 65 fall and approximately half of them experience multiple falls in the same year [13]. The occurrence of falls increases as age progresses and it is the highest among individuals who are 80 years of age and older [13-16].

Five to 10% of the older adults who fall each year experience serious injuries such as bone fractures, head injuries and serious laceration [13]. Studies have found that among older adults, 10% of the visits to the emergency department and 6% of urgent hospitalizations are on account of falls [17]. In older adults, the rate of hospitalization due to a fall is about 5 times more than the rate of hospitalization from any other source of injury [18]. It has also been observed that 20-30% of the falls result in moderate to severe injuries that in turn have an adverse effect on the mobility and independence of an individual [18]. Falls not only have an effect on the mobility of the individual, but they also increase the risk of early death [18]. In 2004, approximately 1.6 million older adults were taken to the emergency departments and 387000 were hospitalized due to falls [19]. In 2003, 12,837 fatalities were caused due to falls among the older adults in the United States [19]. In the year 2000, the US health care system spent about $19 billion as direct medical costs for fall related injuries [6]. Among the older adults living in communities, between 25% to 75% of the population do not recover their pre-fracture level of mobility [20] and remain at high risk of fall in the future [21].

Bone fractures are the most common fall related injury. In most cases, a fall with fracture leads to either a visit to the emergency department or hospitalization. [22, 23]. Topping the list of bone fractures are hip fractures which almost always result in hospitalization and consume a good number of orthopedic beds [24]. Colles' fractures (forearm fractures) are also very common fractures. In fact, they are the most common fractures in women in northern Europe and the United States up to an age of 75 with a lifetime risk of about 15% [25]. Out of 2,132 cases of Colles' fracture, 91.6 % of the fractures were due to a fall [26]. Vertebral fracture is yet another fall related fracture. It has been noted that about 30% of vertebral fractures result from a fall [27].

2.2 Previous approaches to falls

Falls can be classified as falls due to intrinsic (patient related) factors and falls due to extrinsic (environmental) factors. Studies have shown that 41% to 55% of the falls in the community-dwelling older adults of age over 65 years, and about 16% of falls in older adults living in nursing homes are due to extrinsic factors [28, 29]. Intrinsic factors have caused 39% to 53% falls in community dwelling older adults and 80% of the falls in adults living in the nursing homes [28, 29].

Risk factors of a fall

Studies have shown that few falls have a single cause; a majority of them are due to a combination of short-term or long-term intrinsic factors and short-term extrinsic factors [30-34]. Each of the following intrinsic factors have been said to increase the risk of falling in more than two observational studies: arthritis; orthostasis; depressive symptoms; vision, balance, gait, muscle strength, impairment in cognition and the use of four or more prescription medicines. The risk of falling is associated to the increase in the above factors [30, 31].

The core factors in maintaining an upright standing position are the sensory inputs, the central nervous system and the effector response. The summation of physiological change and disease may enhance the intrinsic risk of falling among older adults. Parkinson's disease (PD) is one of the most common examples of a disease that can impair the motor control of the body [35]. It was noted that out of 100 patients with Parkinson's disease, 38% of the subjects fell and 13% fell more than once a week. It involved 13% broken bones, 18% hospitalization, 3% confinement to wheel chair and also patients who were scared to walk in the future [36]. Impaired sensimotor integration, inability of switching between sensory modalities, lack of compensatory stepping may all lead to high occurrence of falls in patients with PD [37]. Patients suffering from rheumatoid arthritis (RA) may also be at a greater risk of falls as they very often experience muscle weakness or stiff joints [38-41]. In RA, joint problems and disturbance in gait due to joint pain and swelling played a vital role as compared to age and muscle volume [42]. Similarly, other diseases that affect sensory mechanism, sensory integration, motor control, and/or muscle strength can increase the risks of falls. Researchers have realized that greater the number of risk factors, greater are the chances of a fall [43]. Though the causes for falls are identified, fall prevention remains a topic in need of discussion.

Prevention of falls

Multi-component group exercises reduced the rate and risk of falling to 0.78 RR (Risk Ratio). Activities like Tai Chi (0.63 RR) and multi-component individual prescribed exercises (RR 0.68) also brought down the rate and risk of falling [44]. Research has found that when psychotropic medications were withdrawn slowly, it reduced the rate of falls [44]. Visual impairment is yet another risk factor for falls. In the first few months after vision assessment, the rate of falls increases [45]. The authors of this research suggested this may be due to adjustment to new glasses or increased activity [45]. Multifocal lenses were also identified as one of the reasons for an increased number of falls as compared to single lens [46]. Occupational therapists have observed the environment in which older adults have the maximum number of falls [47]. These observations have enabled them to design an environment to reduce the number of falls. This has involved taking away hazards and obstacles, adding on better safety devices that make living less stressful, for example, ensuring that the bed is at the appropriate height, improvements in lighting, inclusion of safety alarms etc. These strategies have helped us reduce the number of falls. [47] Studies have demonstrated that a daily dosage of vitamin D supplements helps prevent some falls. A deficiency of Vitamin D is associated to muscle weakness and significantly reduced neuromuscular function in addition to bone health [48]. Other authors have found that flexibility, balance, gait and strength training also have a positive effect on preventing the number of falls [49]. One commonly used device is the use of different kind of alarm systems which is activated as soon as the patient gets out of the bed or moves unassisted. In one of the pilot studies done in an orthopedic clinic and general hospital ward authors saw a drastic reduction in the number of falls by 33% and 45% respectively using such a monitoring device [50].

Impact during a fall

Studying the mechanics of a fall is important to reducing the impact from a fall. Studies have shown that a sideways fall compared to a fall in the anterior/posterior directions increases hip fracture risk 3 to 5 fold [32, 51-54]. Results from another study suggest that during a sideways fall, individuals could reduce the impact on the hip by rotating themselves forward or backward [55]. There is yet another important factor that needs to be considered during a fall. It was found that axial rotation of the lower part of the body towards the non tripped side increased the length of the recovery step in the sagittal plane and this in turn enabled braking during the fall [56].

While several studies have been done to study the dynamics of the hip during a fall, very little has been done to study the arm motions during a fall [9-12]. It has been observed that arm movements are an important element to defend against a fall. Some previous works indicate that the response of the arm muscle can precede the response of the leg muscle and this can lessen the impact of a fall or in some cases even prevent a fall [57, 58]. Arm responses have a number of static and dynamic functions during a fall. First, arms may counter balance the change in position of the body in the direction opposite to the fall [59] or they may generate reaction torques at other joints that may have been affected by the perturbation [60]. Arms may also serve as a protective function by extending itself in the direction of fall so as to avoid impact to other body parts such as the hip or head. Similarly arm movements may also be used to get hold of stable objects so as to prevent a fall or to lower the impact of a fall [59]. Studies showed that protective arm movements changed with age. One study found that arm movements were largest in young adults, smaller in middle aged adults and the smallest in older adults [61]. It was seen that the average shoulder abduction angle was significantly different in the elderly population (3.9 deg) as compared to the younger adults (2.3 deg) [61]. According to some studies, both the type of disturbance and the gait speed contributed to the direction of fall and its impact. Trips and steps down mostly resulted with a fall in the anterior direction with frontal impact irrespective of the gait speed. For a higher gait speed, slips and faints also resulted in forward falls with frontal impact. As the gait speed decreased, slips resulted in either a left/right lateral fall or a backward fall with an impact on the hip or buttocks region and faints resulted in greater number of sideways falls with an impact on the hip [62]. Some of these findings concluded that there was some correlation between the impact location during a fall and the direction of a fall.

Fall detection & injury prevention from a fall

Some risk factors of a fall are unavoidable and hence studies have been conducted to minimize or prevent the injury when a fall occurs. One of the most popular devices for fall injury prevention is the hip protectors. Though these protective pads seemed helpful in nursing home settings, they failed to be successful in community dwelling and non-nursing home settings [63]. Other systems to prevent fall injuries include a wearable inflatable system that is designed to protect from falls. It contains at least one inflatable element that can be worn on the body which during a fall inflates itself to protect the back and hip of a falling body [64, 65]. Some authors designed pre-impact fall detection algorithms that could be integrated in a wearable fall injury minimization system to keep track of the body movement and notify the fall impact reduction device when to activate to minimize or avoid injury during a fall [66]. Studies show that fall prediction system was considered equally important as a fall detection system by adults above 64 years of age. Wearable inertial sensors were more preferred as compared to optical sensor system because of their wide range of use which provides the patients with high level of security [67]. Floor mats that were intended to serve as a device that would protect the body from a fall have also proven to be inefficient and are in fact considered a potential hazard for ambulatory patients, especially those with impaired gaits, using walker and pushing mobile intravenous stands [68].

Though there have been advancements in the area, clear guidance is not available for specifying the right kind of interventions to address the specific kind of population that needs protection.

2.3 Current research on arm motion during a fall

Though there has been a lot of research done to study the relationship between the direction of fall and impact on the hip, little has been done to discuss the relationship (if any) between arm motion and the direction of fall [9-12]. It was found that falls on an outstretched hand are a very important cause for injuries in the upper extremities that includes about 90% of fractures at distal radius, humeral neck and the supracondylar region of the elbow [69, 70]. It was observed that the response of the arm muscles to sudden perturbations showed sensitivity to fall directions and the authors considered these responses as an involuntary balance correcting response [58]. The behavior of arm responses to such situations is still unclear.

2.4 Current study

Vigorous arm movements have been studied after perturbation of gait [71-74] and during upright stance [58, 61]. These studies showed arm muscle response latencies of ~0.8 seconds. Though there are details on arm movements and muscle activation in these studies, the role of these arm movements in preventing a fall or lessening the impact of fall has been unclear. In the current study, we examined patterns of the arm motion during a fall and their relationship with the direction of a fall. Here we analyze the behavior of left/right shoulder rotation, left/right shoulder abduction and left/right elbow flexion in the anterior, posterior and medial lateral directions of fall. The specific aims were to characterize arm motion in response to a fall perturbation and to determine if there was any correlation between direction of fall and movement of both of the arms. It was hypothesized that left/right arm response in lateral falls would correspond to the fall direction and the pattern would reverse for falls in the opposite direction. It was further hypothesized that in anterior/posterior falls; differences in arm motions would exist and be symmetric across both arms. If there was indeed a correlation between the fall direction and arm movements, we could use these findings to study the dynamics of a fall in older adults and to development fall/injury prevention strategies and fall monitoring devices.

Chapter 3 Methods

Controlled falls were created to study initial arm motions as a function of fall direction. The falls were created using a tilting metal platform activated by electromagnets. The direction of the falls depended on the direction of the electromagnet that was deactivated (refer figure 1).

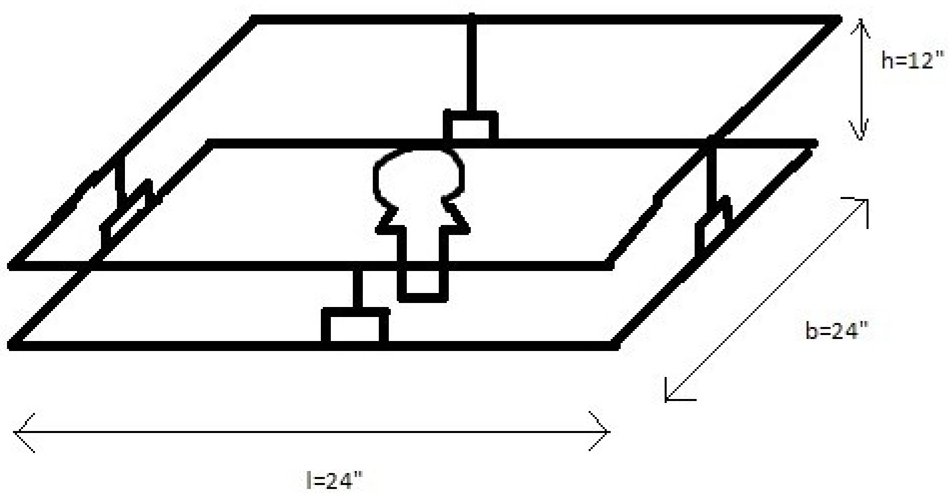


Fig 1: Tilting platform schematic diagram. Figure shows four electromagnets on four side of the platform connected to top plate with a cable. The upward ball indicates a pivot joint that aids the tilting mechanism.

While, falls often occur during gait, in our study, we used the tilting platform to generate a fall from a stationary standing position. The subjects were on the tilting platform in such a manner that the subject could stand on it and experience the artificially simulated fall. The subjects were instructed to let themselves fall onto the gymnastics mat placed around the metal platform. A safety harness which the subjects wore during the course of the data collection period to prevent injury and impact.

3.1 Experimental design of the tilting platform

To determine the minimum thickness required for the top plate of the tilting platform, following calculations were used. For the tilting platform, AISI 1020 with yield strength of 294.8 MPa was considered. The maximum weight of the subject used for the design was 300 lbs which gives us a maximum moment of 1150 Nm.

$$M/I=\sigma_b/y \quad \text{....................(1)}$$

Maximum stress is applied on the top plate of the platform. Hence the above equation can be re-written as

$$\sigma_b = M_b * y/I \quad \text{..(2)}$$

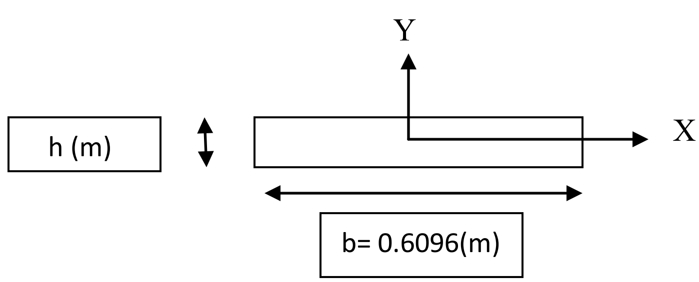


Fig 2: Cross section of the platform. The breadth of the platform is given by 'b' and thickness is given by 'h'.

At the top layer y=h/2 (m) and the moment of inertia for a rectangular section is I=bh^^{3}/12 (m^^{4}).

Therefore, σ_b= M (h/2)/(bh^^{3}/12) = 6Mb/bh^^{2}…………………(3)

Substituting the values of b and M_b in (3)

$\sigma_{b=}$ 6*1150/ (0.6096*h^^{2}) Pa……………………….(4)

Also, σ_b= yield strength/FoS= 294.8 /1.4 (MPa)

⇨ σ_b = 210.57 MPa

Substituting the value of σ_b in (4)

210.57 MPa= 11.32*10^^{3}/h^^{2} (Pa m^$^{-2}$)

Solving for h, we get the minimum thickness of the platform required to be ~7.5 mm or 0.3 inches. The tilting platform was finally made with an aluminum alloy 6061 which had similar properties to that of the steel alloy, but was lighter in weight. To connect the top plate of the platform to the electromagnet on the bottom plate of the platform, springs were initially considered in the design. But, they were replaced by cables in the actual platform due the inconvenience caused while resetting the platform.

The tilting metal platform was designed in such a way that it allowed falls in all directions. Electromagnets were placed on bottom plate of the platform that was in turn connected to the top standing platform using metal cables and small steel plates (refer to figure 3).

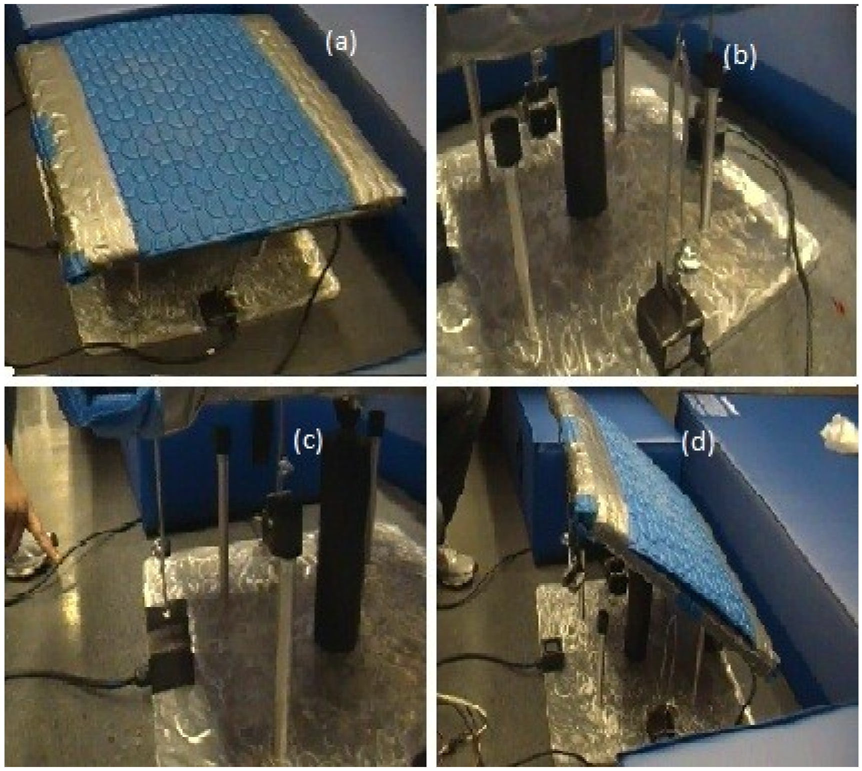


Fig 3 (a)Tilting platform activated by all four electromagnets (top left), (b) Small metal plates connecting to the electromagnet and the top of the platform (top right), (c) Electromagnet to be turned off is shown by the researcher (bottom left), (d) The metal platform tilts once the electromagnet is turned off (bottom right)

The center of the top platform was supported using a pivot on a low friction ball that was located 1.03” under the top part of the platform. When the electromagnets were activated, the steel plates connected to the metal cable the top plate attached themselves to the electromagnet. This made the top plate rest parallel to the bottom plate of the platform. Four 24V, 5.2W square shaped electromagnets (McMaster-Carr, Chicago, IL) were used while designing the stability mechanism for the platform. These electromagnets were connected to the four SPST switches which in turn were connected to the power supply. These switches activated and deactivated the electromagnets depending on their ON or OFF state. Once the activation switches were turned off, the platform tilted and causing the subject to fall.

The tilting platform was made out of aluminum alloy so as to withstand a weight up to 300lbs. The metal plate was 24” x 24” x 0.53” in dimension and the top plate was separated from the bottom plate by a distance of 12”. In order to prevent any injury if the subject landed on the platform, the top plate of the platform was covered using three layers of a dense foam pad. Four gymnastics mat (USA Gym Supply, Great Bend, KS) surrounded the platform to make the landing area safe. There were two mats that were 48” x 24” x 12” in dimension and the other two mats were 72” x 48” x 12” in dimension.

Apart from the soft padded mats, the subjects were also asked to wear a safety harness for additional protection. The safety harness was supported using a harness support that was erected from the ceiling of the laboratory. The harness was set such that, when the subjects let themselves fall freely, they would fall up to a height where their knees would reach the mat. The harness was mounted on elastic cords to prevent abrupt deceleration.

3.2 Protocol

12 subjects (8 male and 4 female) between 18 to 40 years old with an average height of 176.74 ±13.83 (SD) centimeters, weight of 74.88 ±18.15 (SD) kilograms and 24±2.55 years of age were tested with the approval from the Human Subjects Committee at the University of Kansas, Lawrence, KS (Appendix A). Given below is the average height, weight and age of the two categories of subjects.

Subjects	Height (cms)	Weight(kgs)	Age (in years)
e/o	176.16 ±16.08(SD)	74.44±22.62(SD)	24 ±2.97(SD)
e/c	177.33 ±11.60(SD)	75.34 ±13.32(SD)	24 ±2.16(SD)

Table 1: Shows average ± standard deviation of height (in cms), weight (in kgs) and age (in years) of both the e/o, e/c subjects.

The subjects were first asked to fill out a questionnaire to get the general health status and activities information. The details on the handedness of the subjects were also collected. Then, motion data were collected at 100 Hz from six electromagnetic motion sensors (Ascension Technology, VT) using the Motion Monitor software (Innsport, IL). The electromagnetic sensors were placed in six different parts of the body. Two sensors were placed midway between the elbow and the left/right shoulder, two more sensors were placed midway between the elbow and the left/right wrist, one sensor was placed on thorax (T1) and one sensor on the sacrum (between S1 and S2). These six sensors delivered the position and orientation of each of these segments. A Motion Monitor system (Innsport, IL) was used to digitize the joints relative to the sensors so that the joint motion could be accessed. To digitize the segment end point, we used “Digitize joint center by centroid” from the menu. This method creates a “virtual” joint center by computing a “centroid” from multiple readings about a segment endpoint, mostly equal and opposite the shoulder, elbow, and wrist joints. The segment endpoints are triangulated relative to the six degree of freedom of the sensor for the segment (refer figure 4).

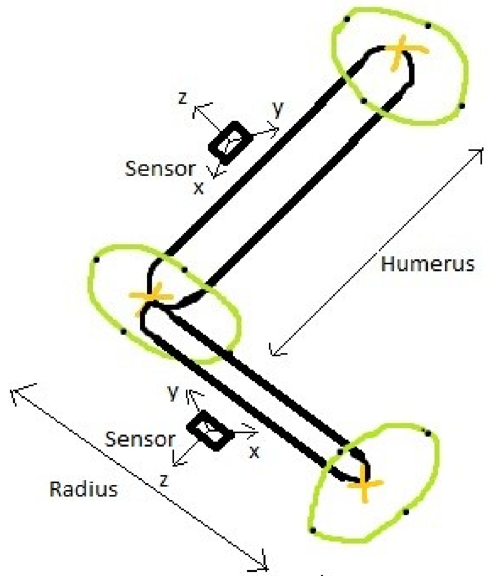


Fig 4: Digitization of joints using motion monitor shows the digitization of segment endpoints to create a virtual joint.

Data were also collected from wrist mounted fall monitoring devices that were strapped around the subject's arm like a wrist watch. These data were collected for a separate study and were not analyzed for this study.

The first 6 subjects performed the trials with their eyes open and the remaining 6 performed it with their eyes closed. Once the sensors were placed in their respective positions, the subjects were hooked up to the safety harness and were made to stand on the platform. The subjects were positioned off center towards the edge of the platform after which the electromagnet was to be turned off. The subjects positioning was done in a series of small steps to prevent subjects from being aware of the fall direction.

There were a total of sixteen trials for each subject out of which four trials were dedicated for each of the four directions (anterior, posterior, left lateral and right lateral). The order of the fall directions was randomized. Although the subjects were asked to remain calm during the study, the subjects did experience various levels of anxiety. To overcome this anxiety, the subjects were involved in general conversations during the study and were asked to answer a few trivia questions. They were also allowed several practice falls.

3.3 Analysis

The data were analyzed to identify any common pattern in arm movements i.e. shoulder abduction, shoulder rotation and elbow flex. The first step in the analysis was to capture the fall initiation timing using the sacrum marker motion (as will be further described in 3.3.2). Using this timing to align the data, arm motions for each fall were analyzed.

The change in angle of arm movements from the initial fall period to the peak of the movement were identified and analyzed on SPSS as a part of the statistical analysis. This determined if there were any statistically significant differences in the arm movements with different fall directions.

3.3.1 Data exclusion

Trials in which sensors moved relative to placement or where data collection failed were repeated. Trials where subjects grabbed the harness were also repeated. Data from six subjects with a history of sports/theatre with fall training (dance, theater, vaulting, wrestling and martial arts) were not included in the subject population listed. Five subjects that failed to be able to follow study instructions due to anxiety or lack of understanding the study (such as grabbing and holding the harness or their bodies) were also excluded. The remaining 12 subjects were used for data analysis.

3.3.2 Capturing the fall

To answer the question of when the fall actually occurred, data from the sacrum marker was examined. The time of fall initiation was assessed by determining when the sacrum motion exceeded three standard deviation from the initial sacrum position measured in the first 0.7 seconds. Figure 3 below shows data from the position of the sacrum marker. Fall was considered initiated in subjects when the sacrum marker began to descend rapidly in the vertical direction from the initial position (shown as a blue circle in figure 5). Once the fall initiations were identified, the data were aligned for each subject for all of their sixteen trials. From this time point, data from the arm motions were assessed for following one second.

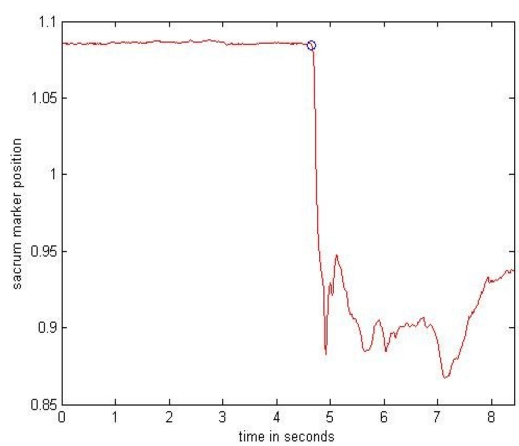


Fig 5 shows the position of the sacrum marker with respect to time. The circle represents the position of the sacrum marker when the fall is beginning to occur.

3.3.3 Assessment of average arm movement patterns

Once the time of fall initiation was identified, movements from upper extremity joints were analyzed. For our study, we examined the data collected from the left/right shoulder rotation, left/right shoulder abduction and left/right elbow flexion. Once the data were temporally aligned, the four trials for subjects in each fall direction were averaged in to a single vector for each of the three measures on each arm. Using this method, the average arm movement was determined for each side (left and right), for each subject and in each fall direction. The subject averages for a given fall direction were combined for a group average. As discussed in the protocol section, one of our subject groups had their eyes open during the fall and the other group had their eyes closed. The average motion in the four different directions for each arm and motion over 1 second were then assessed. In particular, the timing and the magnitude of the peak in motion were calculated. For this, the peak of the subject average was obtained using the max function on Matlab.

3.3.4 Analysis of variance (ANOVA)

Statistical tests were performed on the peak motions that were measured from intrasubject averages of the arm motion patterns for each fall direction and side. The peak motions were analyzed using mixed measures ANOVA with repeated measures of arm side and fall direction and the additional independent non-repeated variable of visual input (eyes open/closed) group. The significance was determined to occur at $\alpha <= 0.05$ (Data table in Appendix D).

Chapter 4 Results

4.1 Assessment of average arm movement patterns

Arm motion analysis was done for three different components that are involved during an arm motion. A) Shoulder rotation B) Shoulder abduction and C) Elbow flexion. The averages of these motions were assessed for the four different fall directions i.e. Anterior, Posterior, Left Lateral and Right Lateral for each arm.

First, looking at shoulder rotation in eyes open subjects (refer figure 6), our graphs clearly indicated a relationship between the left/right shoulders with the fall in the left/right lateral direction. In case of a right lateral fall, a peak was observed of 41.45 degrees (external rotation) for the right shoulder rotation (RSR) as compared to 19.11 degrees (external rotation) for the left shoulder rotation (LSR). In simple terms, the right shoulder tended to rotate itself further as compared to the left shoulder for a right lateral fall. There was a similar pattern that was observed with the left lateral fall as well. For a left lateral fall, the peak was observed at 39.68 degrees (external rotation) for the LSR as compared to 17.61 degrees (external rotation) for the RSR. In the posterior and the anterior fall direction, the shoulder rotations did not seem to show any specific patterns. A similar kind of pattern was observed with the subjects who had their eyes closed during the study (refer figure 7). In case of a right lateral fall, a peak was observed of 23.53 degrees (external rotation) for the right shoulder rotation (RSR) as compared to 17.78 degrees (external rotation) for the left shoulder rotation. For a fall in the left lateral direction, the peak was observed at 30.04 degrees (external rotation) for LSR as compared to 19.47 degrees (external rotation) for the RSR. In the case of shoulder rotation, the right shoulder showed a peak at 0.46 seconds for a right lateral fall and 0.23 seconds in case of a left lateral fall in (eyes open) e/o subjects. Similarly, the left shoulder shows a peak at 0.33 seconds for a right-lateral fall and 0.41 seconds for a left lateral fall in e/o subjects. In eyes closed (e/c) subjects, the right shoulder shows a peak at 0.38 seconds for a right lateral fall and 0.27 seconds for a left lateral fall.

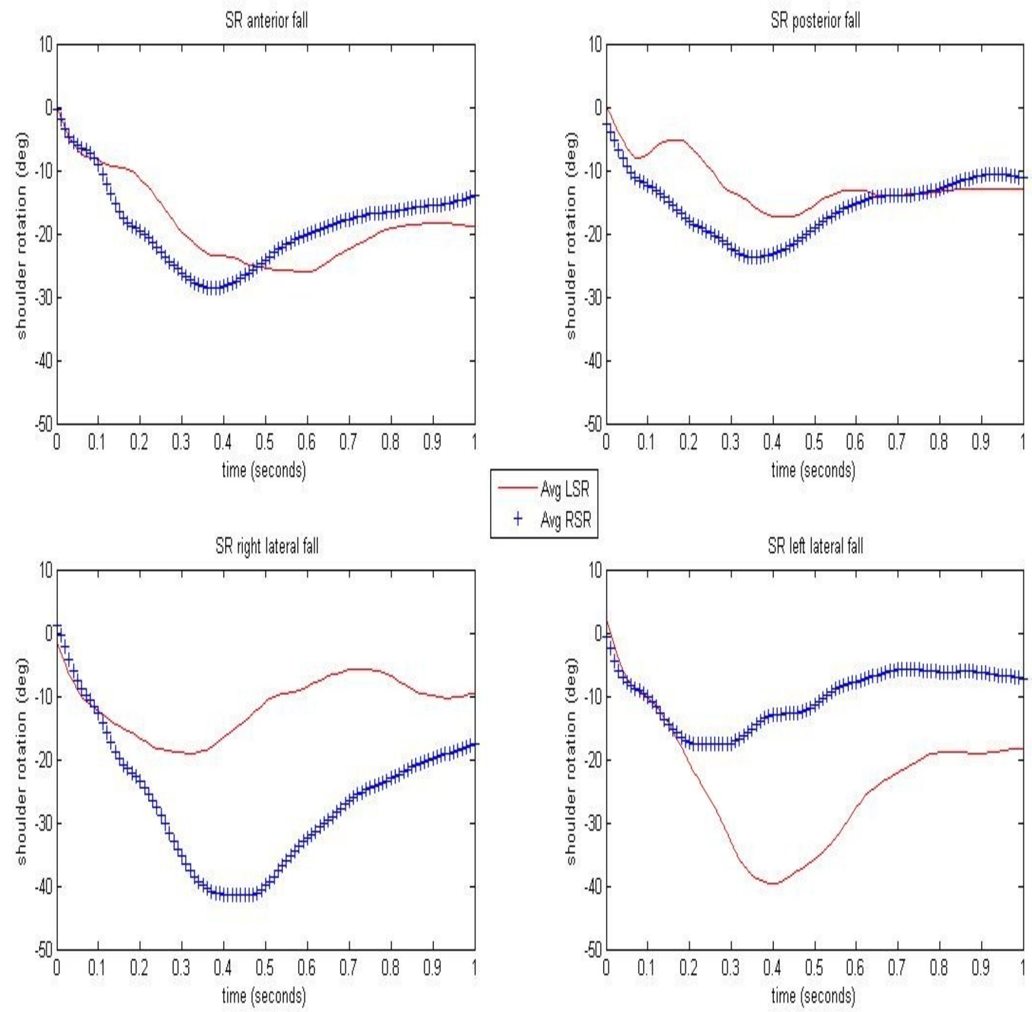


Fig 6 Shoulder rotation (SR) in four directions for eyes open (e/o) subjects. We observe that there is a greater shoulder rotation angle for right shoulder (RSR) during a right-lateral fall and left shoulder (LSR) during a left-lateral fall.

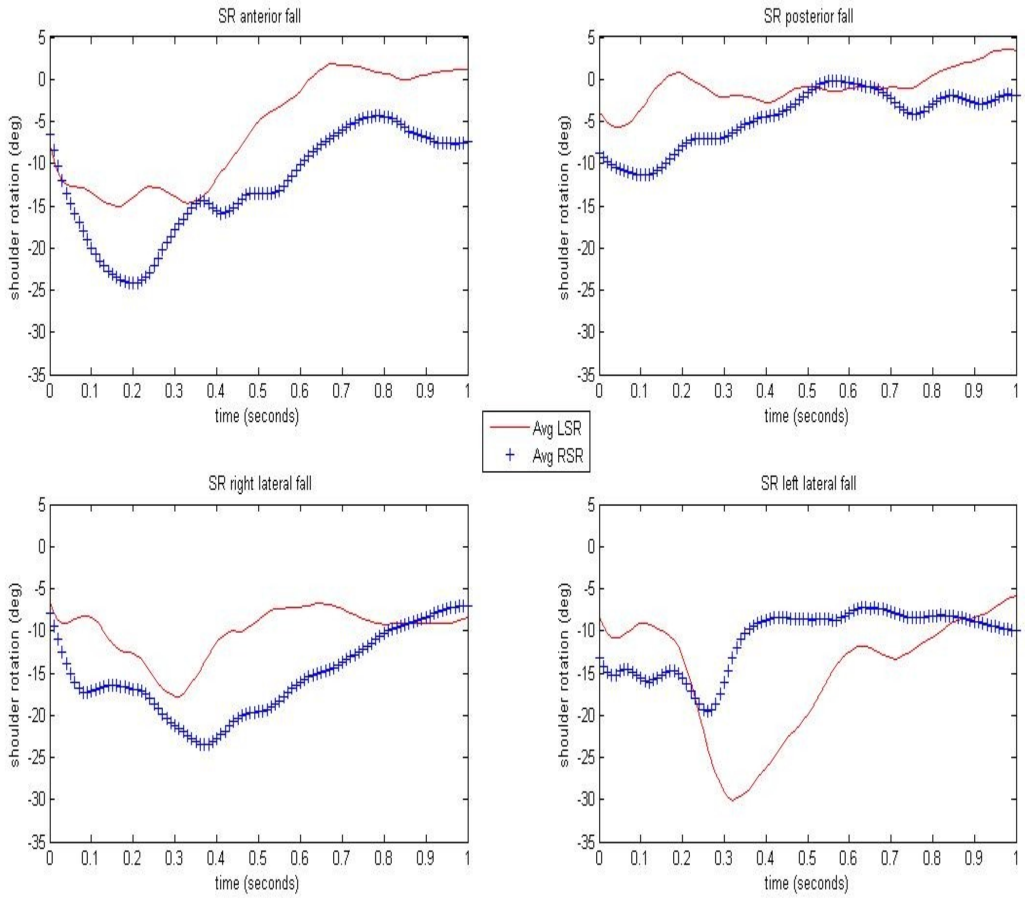


Fig 7 Shoulder rotation in four directions for eyes closed (e/c) subjects. We observe that there is a greater shoulder rotation angle for right shoulder (RSR) during a right-lateral fall and left shoulder (LSR) during a left-lateral fall.

Similarly, data for shoulder abduction/adduction was analyzed to see if there were any direction/side specific findings. For eyes open subjects, peak value for shoulder abduction angle was assessed for the left shoulder as compared to the right shoulder in both left and right lateral fall direction (refer figure 8). Similarly average peaks in the anterior and posterior fall direction were assessed. In general, the angle of left shoulder abduction (LSA) was almost twice that of the angle of right shoulder abduction (RSA). In the anterior fall direction, the left shoulder abduction was 65.78 degrees as compared to 29.38 degrees abduction on the right shoulder. In the posterior fall direction, the angle of abduction on the left shoulder was 65.03 degrees as compared to 30.82 degrees of shoulder abduction on the right side. In the left-lateral fall direction the left shoulder abduction was 77.87 degrees as compared to 32.02 degrees abduction on the right shoulder. Finally, in the right-lateral fall direction, the angle of left shoulder abduction was 58.33 degrees as compared to 39.14 degrees on the right shoulder. For e/c subjects the left shoulder abduction (refer figure 9) for fall in the anterior direction peaked at 44.33 degrees as compared to right shoulder abduction which was 24.4 degrees. In the posterior fall direction, the left shoulder abduction peaked at 52.44 degrees as compared to 28.98 degrees on the right shoulder. In the left lateral fall direction, the left shoulder abduction peaked at 73.37 degrees and 28.70 on the right shoulder. Finally in the right lateral fall direction, the left shoulder abduction peaked at 44.91 degrees as compared to 42.58 degrees on the right shoulder. This pattern was also similar to what was obtained on the e/o subjects for shoulder abduction. In eyes open subjects, the peaking of the shoulder abduction angle for right lateral fall was 0.29 seconds on the left shoulder and 0.30 seconds on the right shoulder. In case of eyes closed subjects, the shoulder abduction angle for a right lateral fall took peaked at 0.28 seconds for both the shoulders.

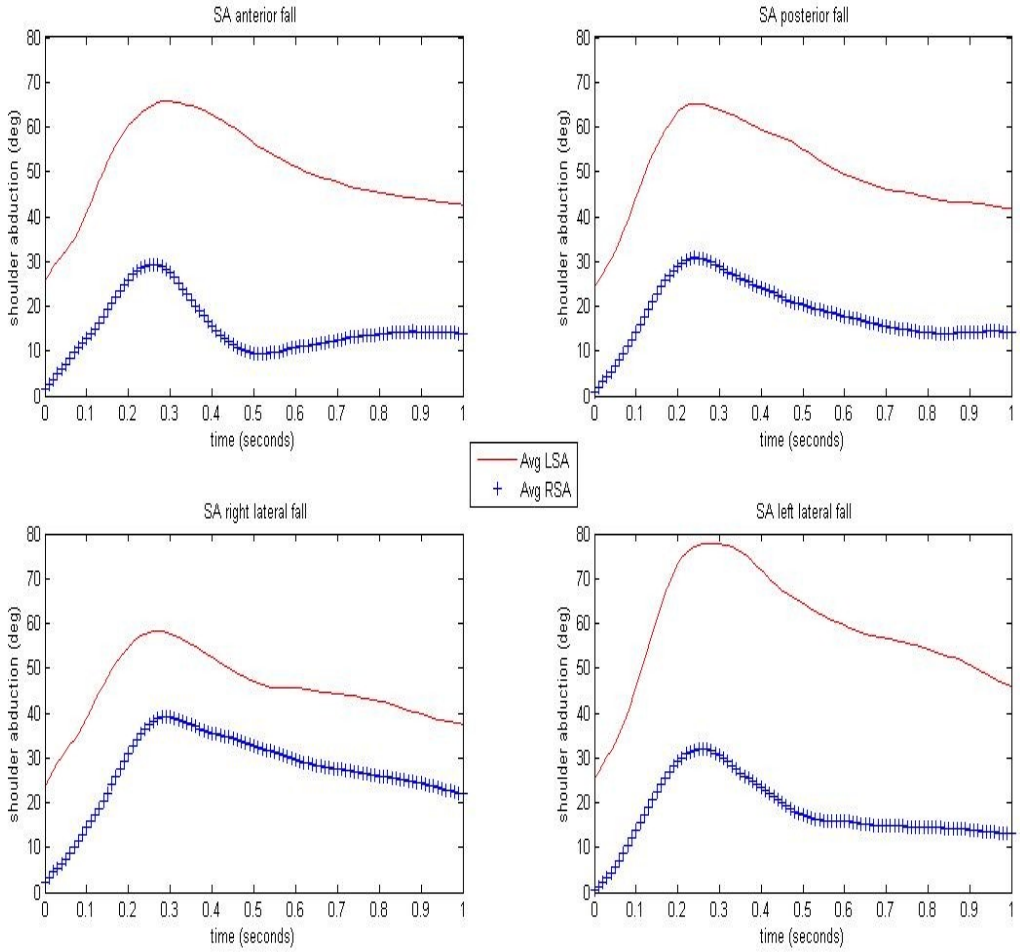


Fig 8 Shoulder Abduction (SA) in four fall directions for eyes open subjects. Plot shows that the angle of shoulder abduction is greater on the left shoulder (LSA) as compared to the right shoulder (RSA).

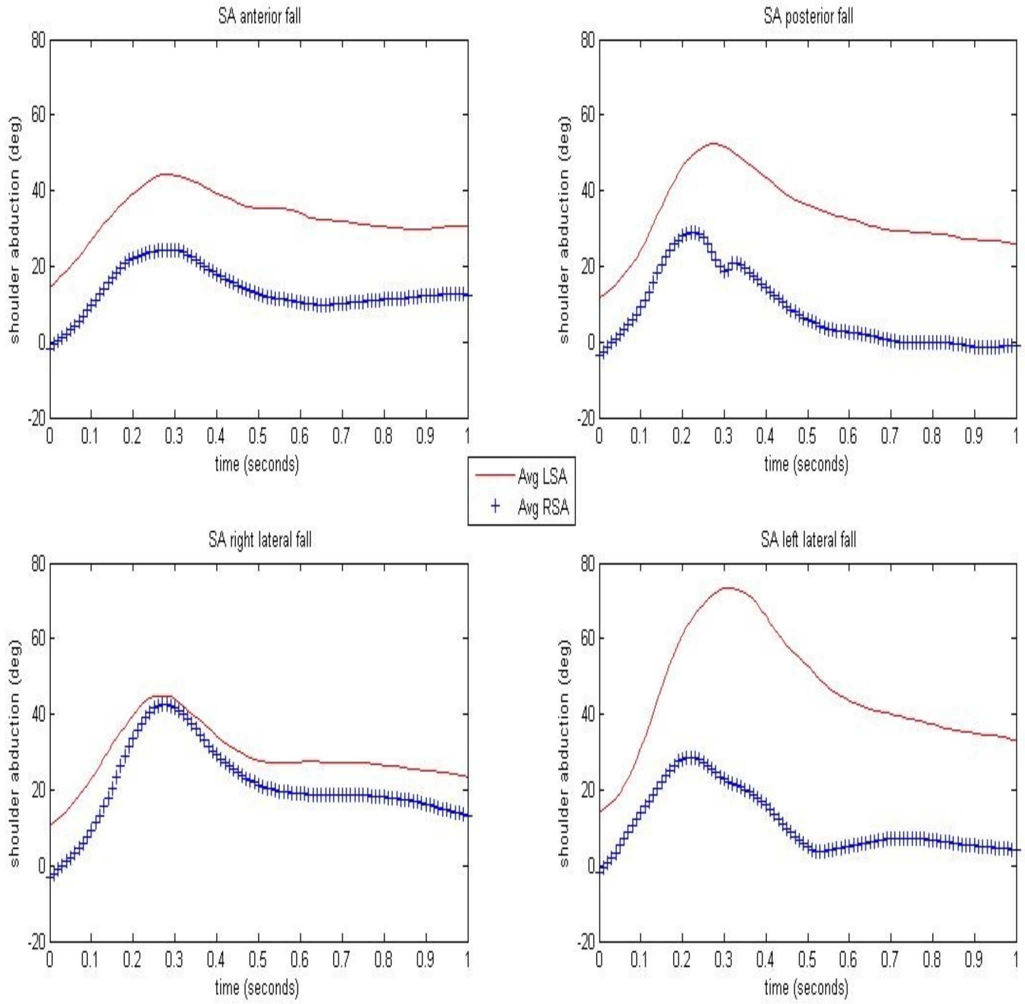


Fig 9 Shoulder Abduction (SA) in four fall directions for eyes open subjects. Plot shows that the angle of shoulder abduction is greater on the left shoulder (LSA) as compared to the right shoulder (RSA).

Lastly, data for right elbow flex (REF) and left elbow flex (LEF) were assessed in all four directions to observe any obvious patterns. It was observed that in eyes open subjects (refer figure 10), the peak elbow flexion angle for the right elbow (average 69.76 degrees) was much greater than the left elbow (average of 45.49 degrees). In the case of e/c subjects, greater elbow flexion was observed on the falling side as compared to the non falling side in the medial-lateral fall directions. In the anterior and posterior fall directions, the angle of right elbow flexion was greater in magnitude as compared to the left elbow flexion. It was also observed that the average peaking time of the right elbow (0.81 seconds) was much delayed as compared to the average peaking time of the left elbow (0.71 seconds).In eyes closed subjects (refer figure 11), it was seen that for right lateral fall there was a delay in peaking for the right elbow flexion and vice versa in case of a left lateral fall. In eyes closed subjects, for the fall in right lateral direction, the right elbow flexion angle peaks at 0.44 seconds as compared to 0.20 seconds for left elbow flexion angle. Similarly, in case of the left lateral fall, the left elbow flexion angle peaks at 0.50 seconds compared to 0.19 seconds for the right elbow flexion angle. In the anterior and posterior directions of fall, greater elbow flexion angle was observed on the right elbow compared to the left elbow.

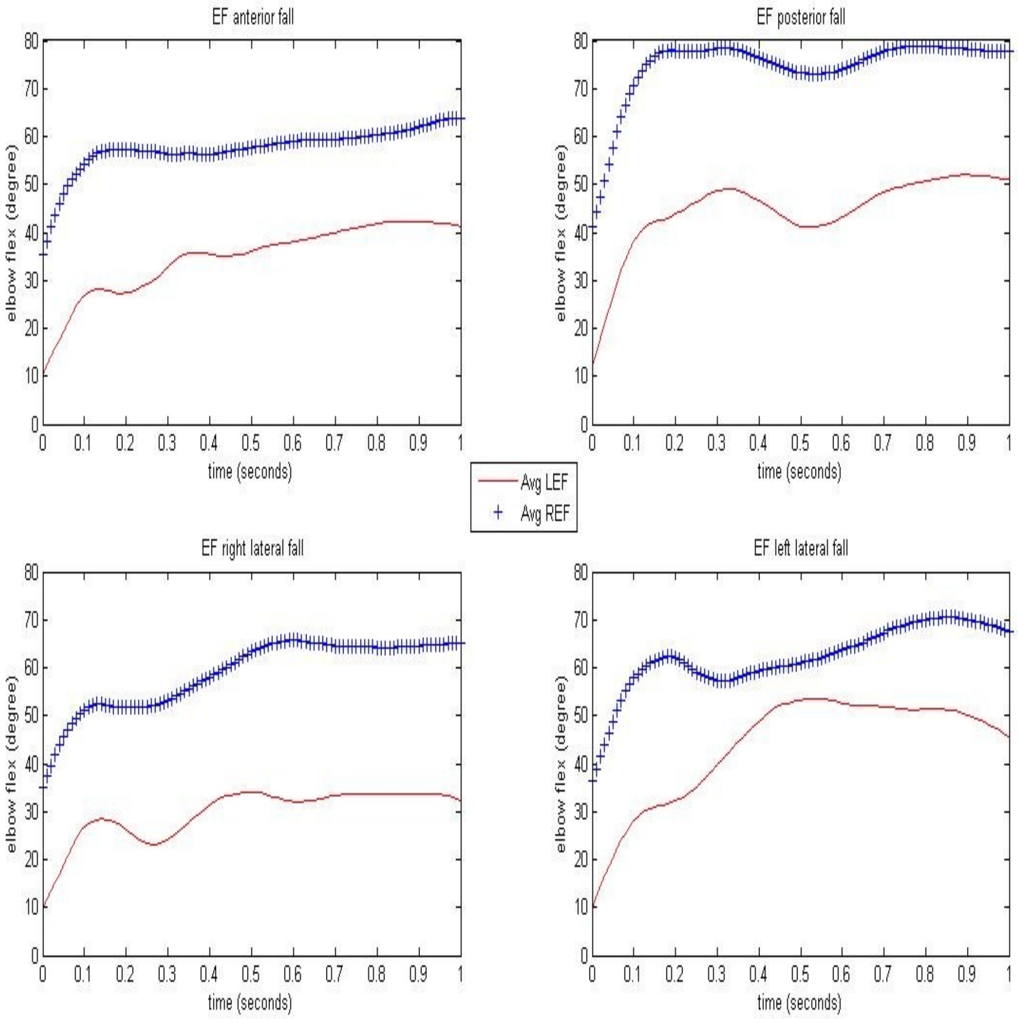


Fig 10: Elbow flex in four directions for e/o subjects. Plot shows that the angle of elbow flexion (EF) is greater on the right elbow (REF) as compared to the left elbow (LEF).

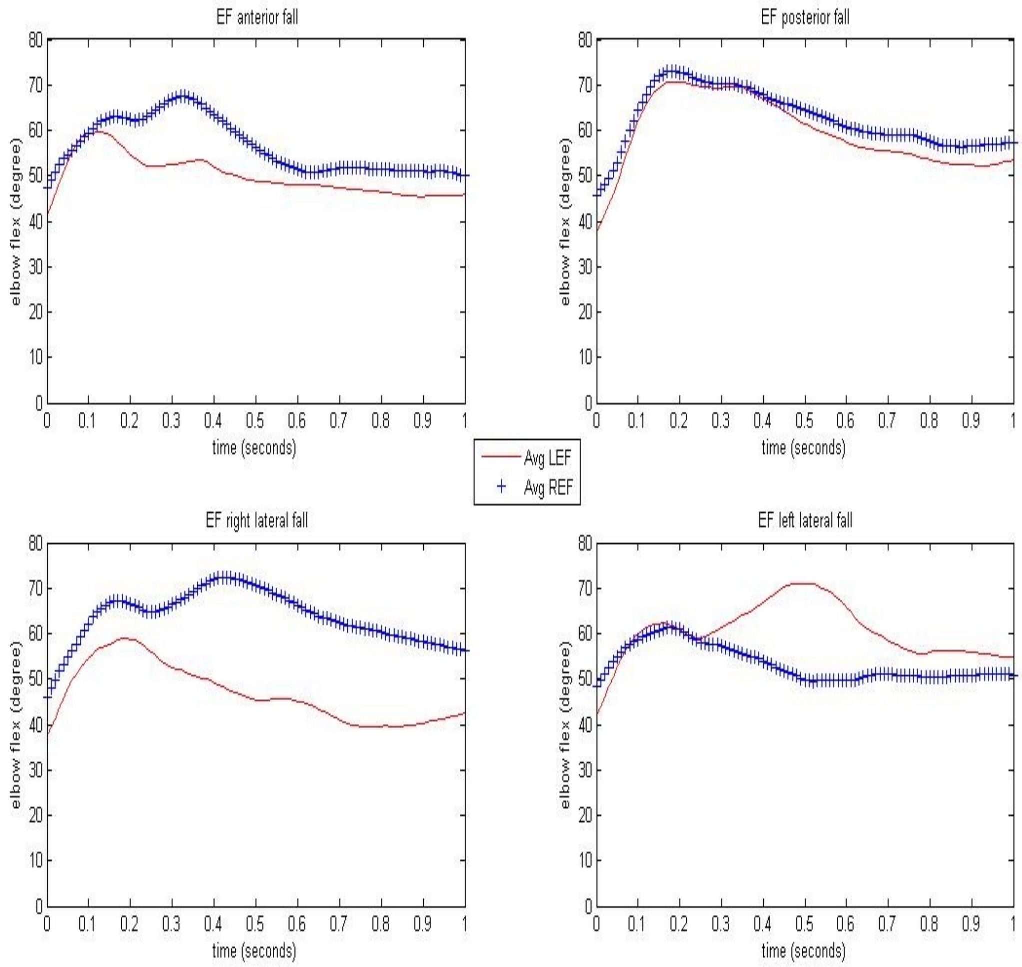


Fig 11: Elbow flex in four directions for e/c subjects. Plot shows a delay in peaking on the right elbow for a right-lateral fall and vice-versa for the left elbow. In the anterior and posterior fall direction great angle of elbow flex is seen for the right elbow compared to the left elbow.

4.2 Analysis of variance (ANOVA)

The analysis examined the falls as pairs to assess the peaks. The first pair involved the comparison of left and right lateral fall directions and the second pair examined comparison of the anterior and posterior fall directions.

Source	Shoulder Rotation(p value)	Shoulder Abduction(p value)	Elbow Flexion (p value)
side	0.606	0.145	0.754
fall direction	0.662	0.329	0.768
eyes	0.115	0.961	0.576
side*direction	**0.026**	**0.002**	0.096
side*eyes	0.432	0.692	0.967
direction*eyes	0.964	0.516	0.172
side*direction*eyes	0.102	0.703	0.556

Table 2 Table showing the p values for various interactions for falls in the left/right lateral fall directions using a mixed measures ANOVA. Both shoulder rotation and shoulder abduction were found to have a significant interaction between side and direction of fall.

Source	Shoulder Rotation(p value)	Shoulder Abduction(p value)	Elbow Flexion (p value)
side	0.227	0.11	0.947
fall direction	0.078	**0.046**	0.995
eyes	0.233	0.954	0.564
side*direction	0.838	0.668	0.238
side*eyes	0.283	0.232	0.553
direction*eyes	0.292	0.174	0.861
side*direction*eyes	0.575	0.282	0.561

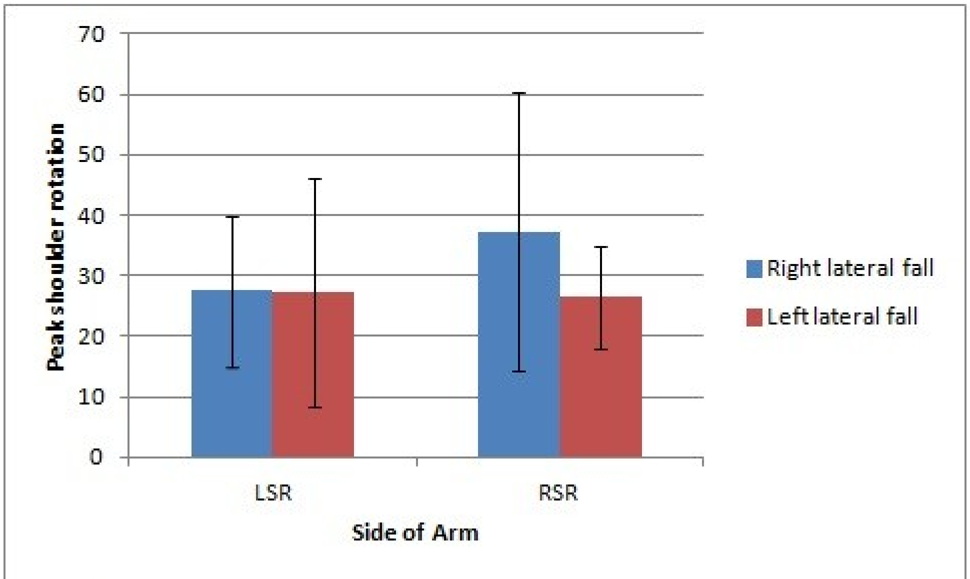
Table 3 Table showing the p values for various interactions for falls in the anterior/posterior fall directions using a mixed measures ANOVA. Shoulder abduction was found to have a significant relationship with fall direction.

Shoulder rotation

The mixed measure ANOVA of lateral falls using repeated measures of arm side and fall direction with a non-repeated independent variable of visual input group (e/o, e/c) showed that the peak shoulder rotation had a significant interaction between the left/right lateral fall directions and arm side measured (side*direction **$p < 0.05$**). The second analysis (anterior and posterior fall direction) found interaction of side of arm rotation and fall direction were not significant (side*direction $p = 0.838$). The plots also showed that there was a significant pattern of more motion on the falling side as compared to the non falling side. There was also a trend seen for more motion on the anterior falls as compared to the falls in the posterior direction (refer figure12).

	lsr AF	lsr PF	lsr RLF	lsr LLF	rsr AF	rsr PF	rsr RLF	rsr LLF
Average	30.48	25.56	27.53	40.54	27.36	23.16	37.3	26.48
Std dev	13.84	8.12	12.41	18.87	14.49	10.63	23.04	8.37

Table 4: Shows average peak & standard deviation of shoulder rotation obtained from all subjects in four directions. Anterior falls (AF), Posterior falls (PF), Right/left lateral falls (R/L) LF. All the values are in degrees.



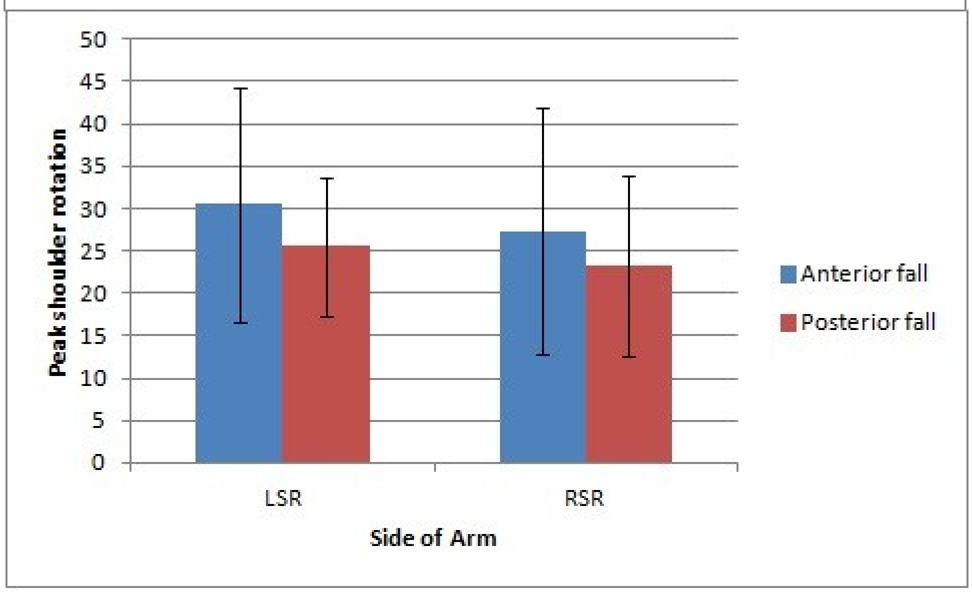


Fig 12: Plot showing peak shoulder rotation with respect to direction in the left-lateral/right lateral fall direction (top), anterior/posterior fall direction (bottom).

Shoulder abduction

In case of shoulder abduction, the ANOVA for the first analysis (left and right lateral fall directions) interactions were significant for the interaction of side*direction (**$p<0.05$**). The fall direction did not seem to follow a trend and was not significant ($p=0.329$). The side of the arm that abducted was shown to be not significant ($p=0.145$). Again, as that of shoulder rotation, shoulder abduction did not show significance for the anterior and posterior fall direction (side*direction $p=0.668$). The plots show that there is a greater motion on the falling side as compared to the non falling side in the medial lateral directions of fall. Similarly, there was also a greater motion observed on the posterior direction compared to the anterior fall direction. In general, there was a trend of greater shoulder abduction on the left side (refer figure 13).

	lsa AF	lsa PF	lsa RLF	lsa LLF	rsa AF	rsa PF	rsa RLF	rsa LLF
Average	39.99	46.27	38.57	57.55	31.71	39.23	45.04	35.27
Std dev	28.34	22.95	26.72	23.21	14.73	12.94	19.48	19.05

Table 5: Shows average peak & standard deviation of shoulder abduction obtained from all subjects in four directions. Anterior falls (AF), Posterior falls (PF), Right/left lateral falls (R/L) LF. All the values are in degrees.

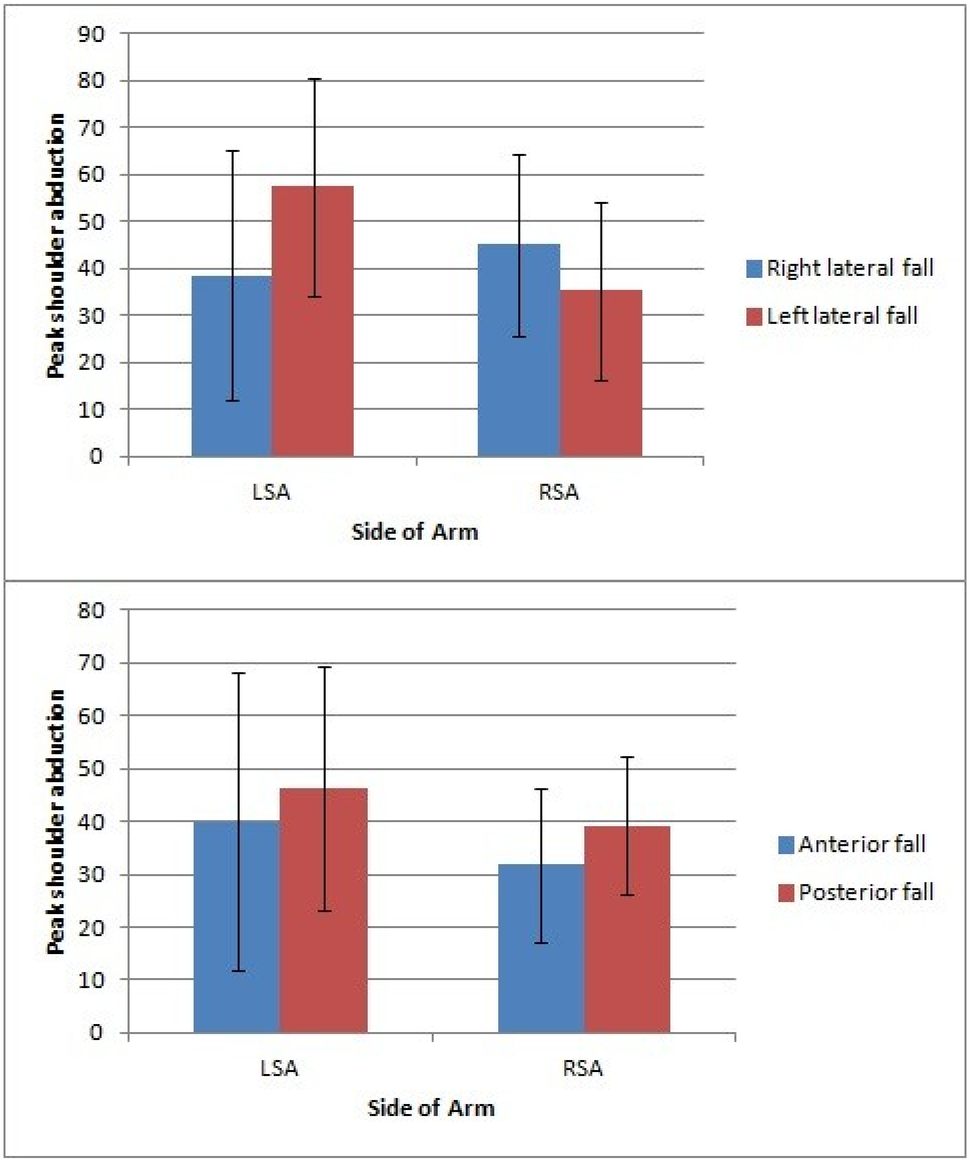


Fig 13: Plot showing peak shoulder abduction with respect to direction in the left-lateral/right lateral fall direction (top), anterior/posterior fall direction (bottom).

Elbow flexion

For elbow flexion both analyses (left/right lateral fall directions and anterior/posterior fall directions) ANOVA showed that the interactions were not significant (side* direction p= 0.096 for left/right lateral fall directions, side*direction p=0.238 for anterior/posterior fall directions). In the case of elbow flexion, a trend of more motion was observed on the falling side during lateral falls (refer figure 14).

	lef AF	lef PF	lef RLF	lef LLF	ref AF	ref PF	ref RLF	ref LLF
Average	42.75	45.39	38.24	46.79	45.08	42.49	47.4	35.84
Std dev	28.57	26.61	15.66	26.01	22.16	27.68	26.39	22.28

Table 6: Shows average peak & standard deviation of elbow flexion obtained from all subjects in four directions. Anterior falls (AF), Posterior falls (PF), Right/left lateral falls (R/L) LF. All the values are in degrees.

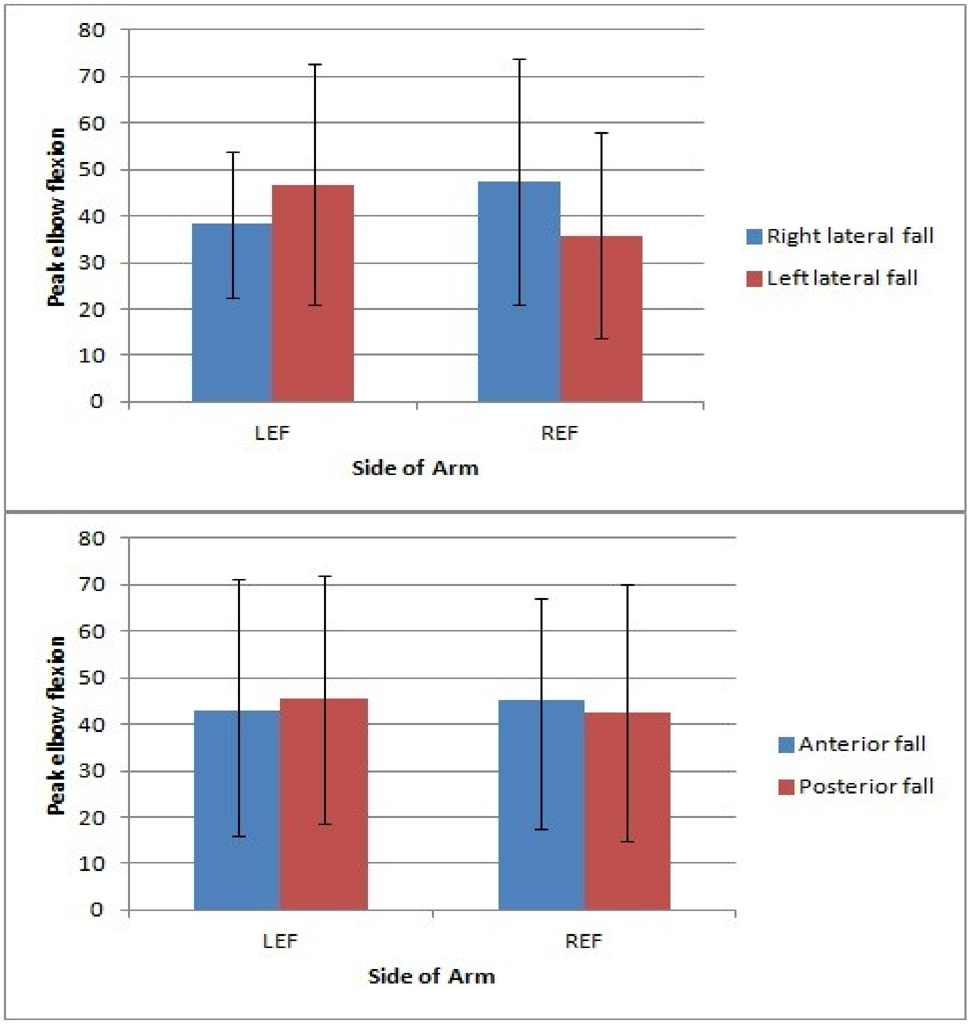


Fig 14: Plot showing estimated marginal means of elbow flexion with respect to direction in the lateral/right lateral fall direction (top), left- anterior/posterior fall direction (bottom).

Chapter 5 Discussion

5.1 Assessment of average arm movement patterns

5.1.1 Timing

Average rotations, shoulder abductions and elbow flexions were analyzed to study the effects of fall direction on the left and right arm motions respectively. Average peak shoulder rotation ranged from .23 to .46 seconds depending on fall direction and arm side. Although previous studies have estimated the balance-correcting response to have an onset latency of 0.1 seconds [61], these peaks ranging from 0.23 seconds to 0.46 seconds is still believed to be a reflex as this is the time to peak response rather than the time to initiation of a response. Previous studies have also shown that amplitude of initial roll velocity of arms is the highest in younger adults and lowest in older adults with the greater the initial roll velocity, placing the arms in a more stable position in case of younger adults [61]. In this study, the average peak shoulder abduction time was 0.29 seconds for falls on the left and right lateral directions. A study has indicated that the reflex response time for the shoulder abduction is 0.11±0.09 seconds [75]. The reflex response time was measured using different manual muscle test and did not involve any sort of fall initiation. There could be a slight variation in the reflex time as the cited study used manual muscle tests to measure the reflex times of muscles.

The same study has also demonstrated that the reflex time for elbow flexion is close to 0.16±0.12 seconds [75]. But the cited study did not take in to account the directions of fall.

5.1.2 Magnitude

Greater magnitude of average peak shoulder rotation angle was observed for the falling side during the lateral falls. In the posterior and the anterior fall direction, the shoulder rotations did not seem to show any specific patterns. A similar kind of pattern was observed with the subjects who had their eyes closed during the study. In general, the angle of left shoulder abduction (LSA) was greater than the angle of right shoulder abduction (RSA) in all the directions. This was a surprising considering that all our subjects were right handed.

It was observed that in eyes open subjects, the elbow flexion angle for the right elbow (average 69.76 degrees) was much greater than the left elbow (average of 45.49 degrees). There was no specific pattern in the peaks that was observed in eyes closed subjects for falls in the anterior and posterior direction. In eyes closed subjects, elbow flexion was greater on the falling side during falls in the lateral directions

5.2 Statistical Analysis (ANOVA)

Statistical analysis was performed on peak motions of intrasubject averages for fall direction* side of arm. Plots showed greater motion on the falling side during lateral falls for shoulder rotation. The results seen here is similar to another study that concluded that arms moved more on the fall direction side as compared to the arm on the opposite side [56]. In the case of shoulder abduction, generally greater motion was seen on the left side except for a fall in the right lateral direction. It was also observed that shoulder abduction was greater on the falling sides during the lateral falls. Studies have found that when falls occur with shoulder abductions, it reduces the stress around the acromioclavicular joint and this in turn minimizes the risk of injury [12]. Previous studies indicate that elbow flexion decreases the maximal axial force of the elbow, delays the time of peak force and hence may help to avoid an injury [10]. In this study, the elbow flexion was also observed to be greater on the falling side in the lateral directions. Greater arm motions in fall direction could be to avoid injuries or dampen the effect of injuries by allowing the body to perform during falls.

5.3 Study strengths and limitations

This study is one of the very few studies that have been conducted to analyze the arm motions of an individual during fall initiation. Though there have been studies that discuss individual components of the arm during a fall, this study is the first of its kind to the best of our knowledge to study various components of arm motions during a fall in four different directions [9-12]. This study involved collecting data from younger adults to analyze the arm motions during a fall. One of the limitations of the study was that it was not conducted on older adults. However, the data that were collected from the younger adults can be extrapolated to aging population. Research has shown that shoulder rotation strength in men dropped down significantly in the over 60 age group [76]. It was observed that older adults used large arm elevations to aid them in trunk stability during a fall [77]. The falls simulated in this study were as close as possible to the falls that occur daily. This gave us an opportunity to analyze falls that mimicked the tripping motion of a standing subject. One of the biggest limitations we had in the study was the presence of safety harness. Though it was designed to not affect any arm motion data, it certainly acted as a "holding harness" for some subjects. This meant that the subjects would grab the harness instead of freely letting themselves fall. Subjects that held the harness were asked to repeat the trials and not to grab the harness. While subjects who could not fall without grabbing the harness were excluded from the study, and trials in which a subject grabbed the harness were repeated, the presence of the harness may have affected arm motion. The harness also limited the extent of the fall so only initial motions are likely to be normal fall motions. The harness was set such that it engaged when the trunk dropped a distance that would allow knee contact with the platform. Anxiety and expectation of the fall may also have an influence on the arm motions. Subjects generally had a drop in their fear level after a few practice falls and the subjects were distracted throughout the experiment by being engaged in conversation, but for some even the conversation was not of much help in reducing anxiety. Subjects with eyes open during the study found falling to be a little more comfortable than the subjects who had their eyes closed. Though the direction of fall was randomized, the subjects could predict the direction of fall. This could have also been a source to alter arm movements. On the whole, while there were some limitations to the study, the study is unique in analyzing four different fall directions as a factor that could affect the arm movements. If the study is conducted on the older adults with a few modifications, it would make way to new fall prevention strategies and fall monitoring devices that would increase the quality of life.

5.4 Future work

Although the study has applications to fall issues in older adults, only younger adults were recruited. The same study with a few modifications could be used for older adults in the future to examine the arm movements. Our study did not use EMG to study the muscle activation/deactivation. This could be another area of research to see the muscle activations pattern during a fall. Some of the muscles that are involved in arm movements are the deltoid muscle, infraspinatus, teres minor, teres major, and subscapularis. Examination of these muscles involved in internal and external movements of the arm might give us a better idea of its dynamics in younger and older adults during a fall. Six of our subjects were eliminated from the study due to their history of fall training. In the future, we could use these subjects to study the effects of training on arm motions. One other area of research could be to analyze the arm motions during a fall without the safety harness. As discussed above in the limitations, safety harness limited the full extent of the fall. Analysis of arm motions in different age groups can pave ways to more research in fall monitors. Fall monitors areas of research that when fully developed can aid the older adults to lead an independent and secure life.

5.5 Conclusion

This study is one of the very few studies that have been performed to analyze the arm motions during a fall to the best of our knowledge. The specific aims were to characterize arm motion in response to a fall perturbation and to determine if there was any correlation between direction of fall and movement of both of the arms. It was hypothesized that left/right arm response in lateral falls would correspond to the fall direction and the pattern would reverse for falls in the opposite direction. It was further hypothesized that in anterior/posterior falls; differences in arm motions would exist and be symmetric across both arms. It was seen from the analysis that the greater shoulder rotation was observed on the falling side as compared to the non falling side for a fall in the lateral directions. It was also observed that there was a greater shoulder rotation for anterior falls compared to the posterior falls. For shoulder abduction, greater motion was seen on the falling side during lateral falls. There was greater shoulder abduction for a fall in the posterior direction compared to a fall in the anterior direction. In the case of elbow flexion, greater angle of flexion was seen on the falling side as compared to the non falling side for the falls in left and right lateral directions.

Chapter 6 Summary of Study

6.1 Introduction

Falls are serious problem that older adults experience in all parts of the world. The number of fractures resulting from falls is low, but the absolute number of older adults who suffer from fractures is high and relies a lot on the health care system [78]. Fall related visits to ED ended in 860,000 hospitalizations, 62 % of which were patients above 65 years of age [79]. Mortality due to falls increased with age (23.19% for 65-69 years and 53.53% for 85+ years), and the proportion of fall related mortality was higher in women as compared to men (46.9% vs. 40.7%) [80]. The effects of a serious unintentional fall include visits to the ED, hospitalizations, rehabilitation and in worst case even mortality and it is important to study its nature in older adults to help them lead an independent life. The specific aims were to characterize arm motion in response to a fall perturbation and to determine if there was any correlation between direction of fall and movement of both of the arms. It was hypothesized that left/right arm response in lateral falls would correspond to the fall direction and the pattern would reverse for falls in the opposite direction. It was further hypothesized that in anterior/posterior falls; differences in arm motions would exist and be symmetric across both arms.

6.2 Methods

12 subjects (8M &4F) between 18 to 40 years were tested with the approval of the human subjects committee at the University of Kansas. Controlled falls were created using a tilt metal platform to study the arm movements during a fall in different directions. The subjects were asked to let themselves fall once the platform tilted to any of the four directions. Motion data was then collected at 100 Hz from six electromagnetic motion sensors (Ascension Technology, VT) using the Motion Monitor software (Innsport, IL). These sensors collected motion data during falls in four different directions: anterior, posterior and medial-lateral fall directions. Arm motions that were assessed included 1) Left/Right shoulder rotation 2) Left/Right shoulder abduction 3) Left/Right elbow flexion. Two methods were used to analyze the data: 1) assessment of average arm movement patterns 2) analysis of variance (ANOVA). The "Assessment of average arm movement patterns" method helped us to determine if there were any correlation between the direction of fall and the behavior of 1) Left/Right shoulder rotation 2) Left/Right shoulder abduction 3) Left/Right elbow flexion. The average of each of these arm movements in each direction with respect to time was determined by averaging four falls in each direction for each subject and then averaging patterns for each subject group (eyes open and eyes closed). The statistical analysis used mixed measures of ANOVA with repeated measures of arm side and fall direction and an additional independent non-repeated variable of visual input group (eyes open/eyes closed) to determine if there was any significance effect of the direction of fall, the side of the arm and the visual input on peak arm motion on the first second of the fall.

6.3 Results and discussion

Analysis of the data by assessing the average of arm movements and the analysis of variance in the four directions of fall demonstrated that there was a correlation between the side of arm moved and the direction of fall. It was seen from the analysis that during shoulder rotation, there was a significant increase in magnitude of peak on the fall side as compared to the shoulder on the opposite side of fall in the left and right lateral directions. There was nothing in specific that was observed in case of the falls in the anterior and posterior direction. In case of the shoulder abduction, the peaking was greater on the left shoulder as compared to the right shoulder in all four directions. For a fall in the left and right lateral directions, the peak of the elbow flexion angle was found to be greater on the falling side as compared to the opposite side. Analyzing the variance in the left and right lateral fall directions with repeated measures of side of arm and fall direction and an additional independent non-repeated visual input, demonstrated a significant difference ($p<0.05$) between the two fall directions. In anterior and posterior fall directions, the interactions between the side of the shoulder and the direction of fall were not significant. In case of shoulder abduction the interactions between the side of the arm abducting and the direction of fall were significant in the left and right lateral directions. The elbow flexion patterns though not significant showed a trend that agreed with the assessment of average method.

On the falling side, the difference in magnitude of peaking arm movements could be a mechanism for avoiding falls. In other words, greater the performance during a fall initiation, greater would be the chances avoiding injury or to reduce the severity of the injury. Reducing the performance during a fall event would increase the force of impact with which the subject would hit the ground.

6.4 Conclusions

Several studies have been done in the past to study the causes leading to injury from falls, but little has been done to examine the effect of arm movements during a fall [9-12]. This study shows that the patterns in which the arms move are dependent on the direction of fall. It all leads to a conclusion that greater the performance during the fall, lesser would be the impact and greater would be the chances of avoiding an injury. The assessment of average method played a very important role in identifying the relationship between the direction of fall and the movement of the arms. The analysis of variance additionally demonstrated significance between the interaction of side of arm and fall directions in the medial-lateral fall directions with a visual input as independent non-repetitive variable. This study was helpful in studying the dynamics of arm motions during a fall initiation. This study with a few modifications would enable more researchers to develop strategies to avoid fall related injuries and also develop fail-proof fall detecting/monitoring devices.

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Appendix

A Subject Consent Form

Given below is the consent form that was developed to explain the study to the subjects. The subjects were asked to sign on two copies out of which one was retained by the subject and the other was given to the experimenter. This form contained all the required details about the study and the contact information of the principal investigator for any questions or concerns after leaving the study.

A Low-Cost Fall Monitor for Geriatric Subjects

INTRODUCTION

The Department of Mechanical Engineering at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

We are interested in evaluating a device that monitors how and when a person falls. This device will be used to monitor if elderly people fall and will be able to call for medical assistance.

PROCEDURES

If you choose to participate, we will first give you a health questionnaire to make sure you do not have any heart problems or back injuries that might make it difficult to do the experiment.

Magnetic markers will be taped or strapped to your arms and at your hips. The markers are used to sense how you move. In addition we will have you wear a wrist watch like device that contains sensors that measure how you move. While wearing these markers, you will be asked to stand on a platform surrounded by soft mats. After a short period of time the platform will be released and you will feel the sensation of slipping. We will ask you to let yourself fall onto the soft mats. We will have you repeat these falls sixteen times with the slipping sensation in different directions. During this experiment you will be asked to wear a safety harness to avoid injury. Your participation is strictly voluntary and you can stop at anytime. We assure that your name will not be associated in any way with the research findings.

RISKS

Precautions will be taken to insure that falls are performed as safely as possible. While mats and protective harness will reduce the risk of injury from a fall, it is still possible that someone may react to the fall with abnormal muscle activity and experience muscle soreness. In addition, like any physical activity there may be unforeseen injury risks. In addition, some people have allergies to adhesives such as in band-aids or in the tape we are using to attach the markers.

BENEFITS

With this research we hope to be able to develop a system that can track when someone falls. This will be used to monitor elderly people to determine how and when they fall. There is, however, no direct benefit for the subject of this study.

PAYMENT TO PARTICIPANTS

Subjects will receive $40 for participation in the study.

INFORMATION TO BE COLLECTED

To perform this study, researchers will collect information about you. This information will be obtained from a questionnaire that will assess if you have heart or musculoskeletal problems that might make exercise inadvisable. Also, information will be collected from the study activities that are listed in the Procedures section of this consent form. This includes information about movements, your height and your weight.

Your name will not be associated in any way with the information collected about you or with the research findings from this study. The researcher(s) will use a study number instead of your name.

In addition, Dr. Wilson and her team may share the information gathered in this study, including your information, with the National Institute of Health that is funding the study. Again, your name would not be associated with the information disclosed to these individuals.

In addition, the information collected about you will also be used by the company that created the measurement device (Barron Assoc.) to let them know how well their device works. Again, your name would not be associated with the information disclosed to these individuals. Some persons or groups that receive your information may not be required to comply with the Health Insurance Portability and Accountability Act's privacy regulations, and your information may lose this federal protection if those persons or groups disclose it.

The researchers will not share information about you with anyone not specified above unless required by law or unless you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

INSTITUTIONAL DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose information collected about you, in writing, at any time, by sending your written request to: Dr. Sara Wilson, Mechanical Engineering, University of Kansas, Lawrence, KS 66045. If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use and disclose information that was gathered before they received your cancellation, as described above.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study and the use and disclosure of information about me for the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7563, email dhann@ku.edu.

I agree to take part in this study as a research participant. I further agree to the uses and disclosures of my information as described above. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_______________________________ _____________________

Type/Print Participant's Name Date

____

Participant's Signature

Researcher Contact Information

Sara E. Wilson

Principal Investigator

Mechanical Engineering

3013 Learned Hall

University of Kansas, Lawrence, KS 66045

785 864-2103

B Questionnaire

Human Motion Control Lab

P.I: Dr. Sara E. Wilson **Title: A Low-Cost Fall Monitor for Geriatric Subjects**

Graduate Student: Bhargavi Krishnan **Date:**

1. Age :
2. Sex :
3. Height (in cms) :
4. Weight (in lbs) :
5. Medications (If any) :
6. What is your race? (For statistical purpose only)

Hispanic Asian White Afro-American Others

7. Do you have any symptoms of osteoporosis that include bone tenderness, fracture, loss of height, low back pain etc?

8. Did you undergo any back injury/ surgery in the past 6 months?

    Yes No

9. Do you have any history of cardiovascular (heart) disease?

10. Have you ever had any of the following (circle any that you have experienced)?

- Prolapsed Heart Valve
- Heart Murmur
- Myocardial Infarction (heart attack)
- Angiography

- Chest Pain
- Hypertension (high blood pressure)
- Shortness of Breath on Exertion
- Pulmonary (lung) Disease
- Dizziness on Light Exertion
- Claudication (pain in arms and legs during light exertion)
- Diabetes
- Fainting
- Seizures

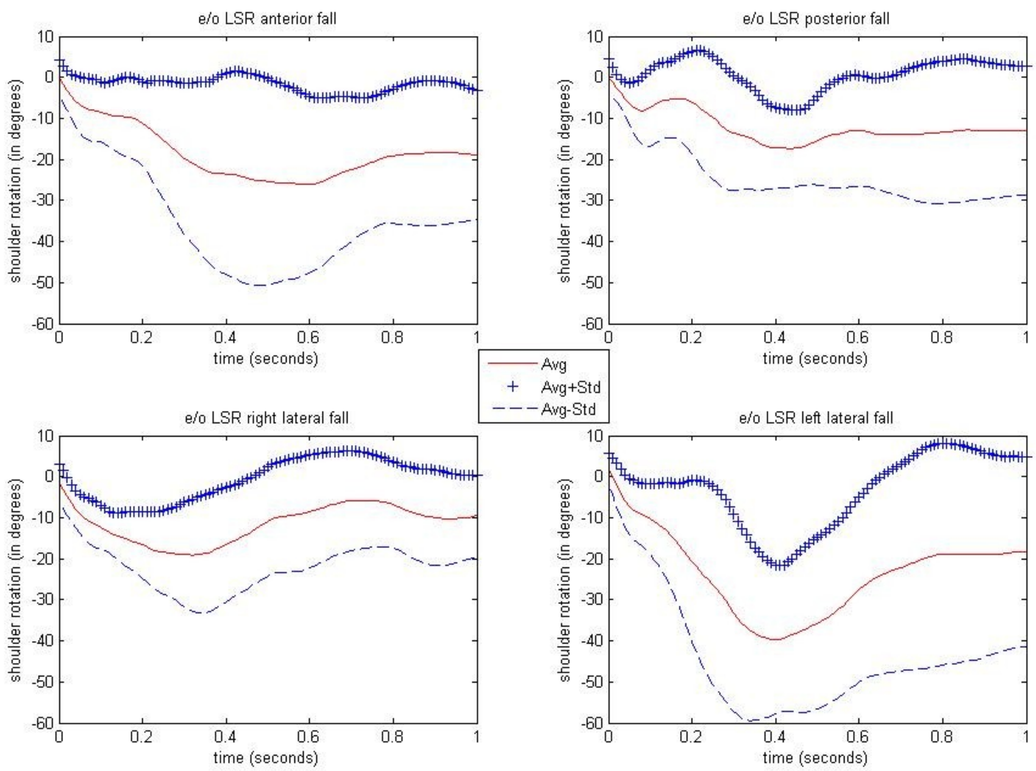
11. Have you ever had pain in your low back for more than one week? Have you had any instances of low back pain within the last year? If yes, describe.

12. Do you currently have any musculoskeletal injuries (sprains, broken bones, sore muscles…)? If yes, describe.

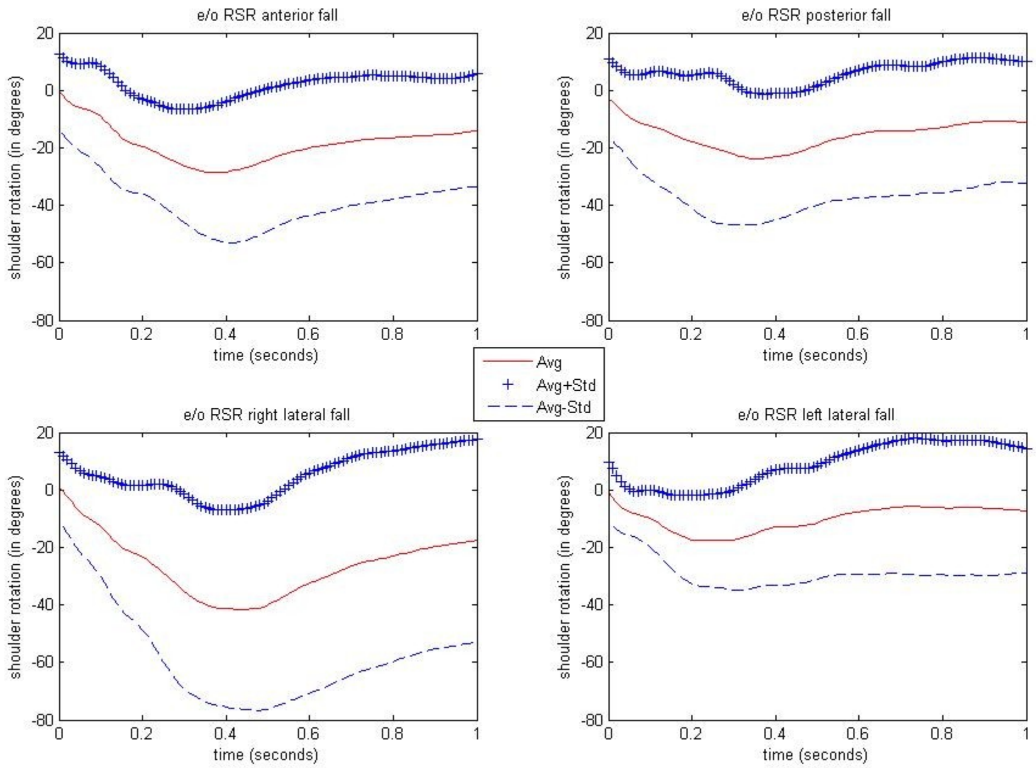
13. When was the last time of your meal?

C Averages and Standard Deviations

The averages and standard deviations were obtained for each group of subjects in all four directions.



The above figure shows the average, average ± standard deviation for Left Shoulder Rotation (LSR) in the four different fall directions for eyes open subjects.



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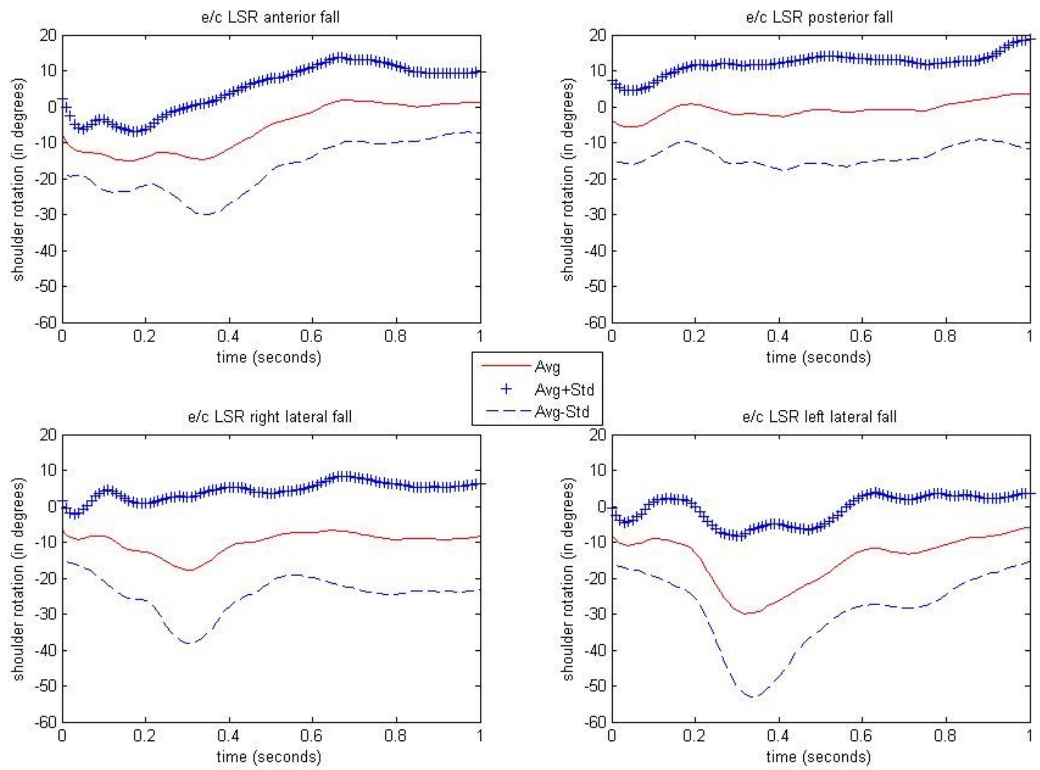
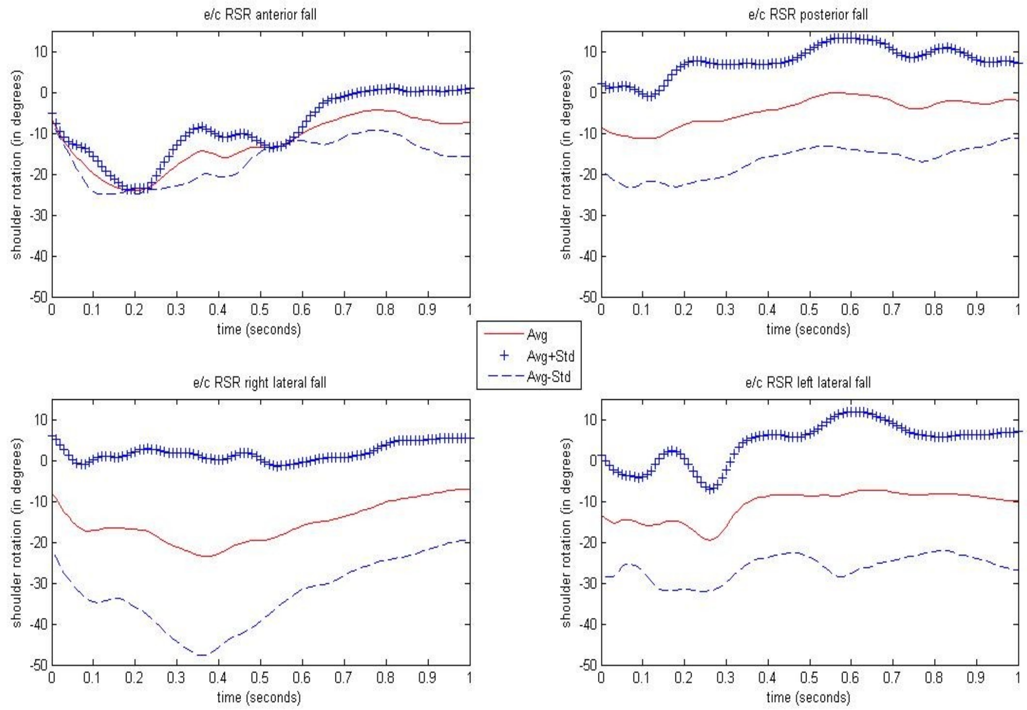
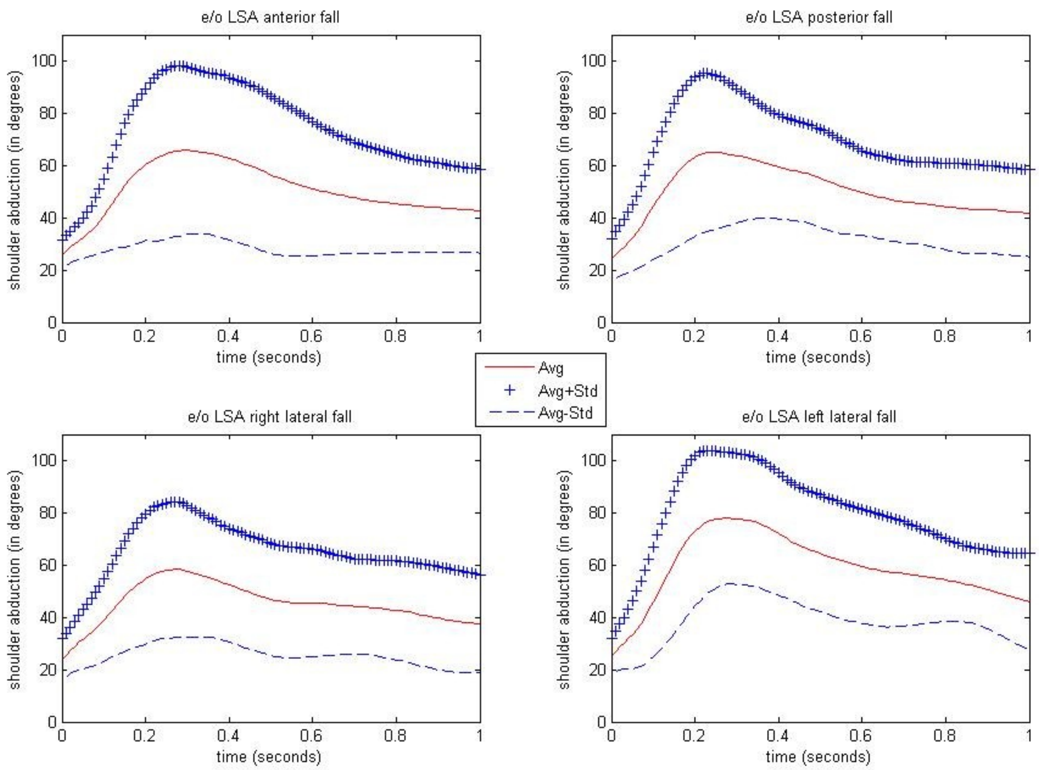


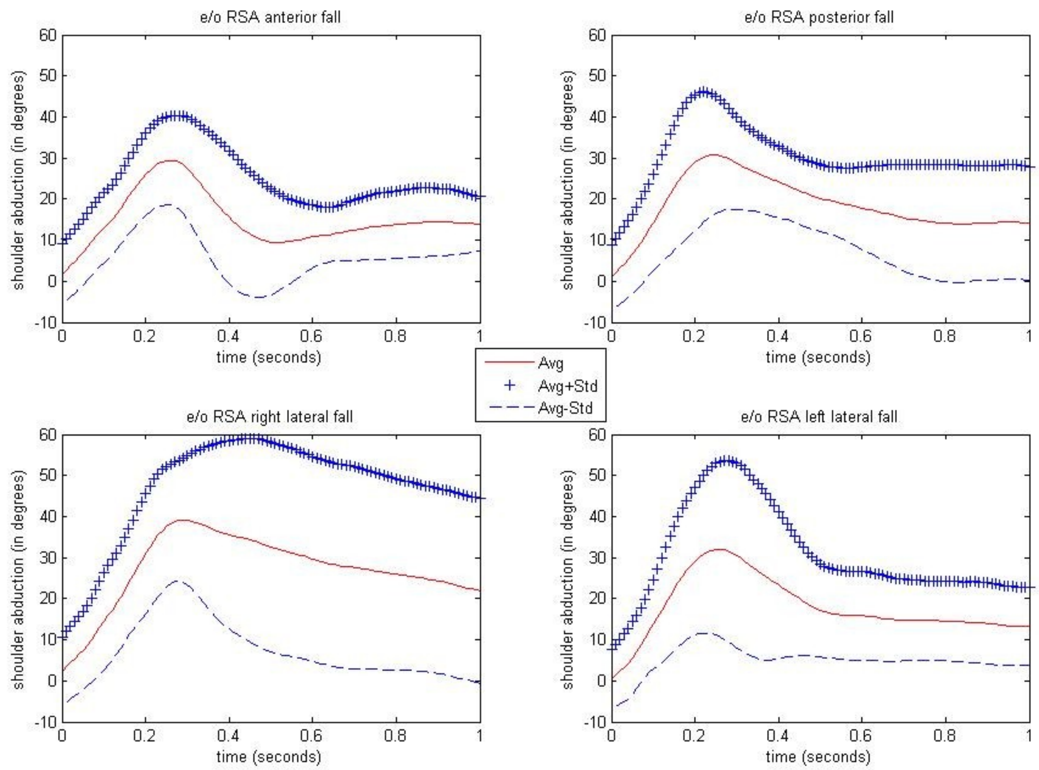
The above figure shows the average, average ± standard deviation for Left Shoulder Rotation (LSR) in the four different fall directions for eyes closed subjects.



The above figure shows the average, average ± standard deviation for Right Shoulder Rotation (RSR) in the four different fall directions for eyes closed subjects.



The above figure shows the average, average ± standard deviation for Left Shoulder Abduction (LSA) in the four different fall directions for eyes open (e/o) subjects.



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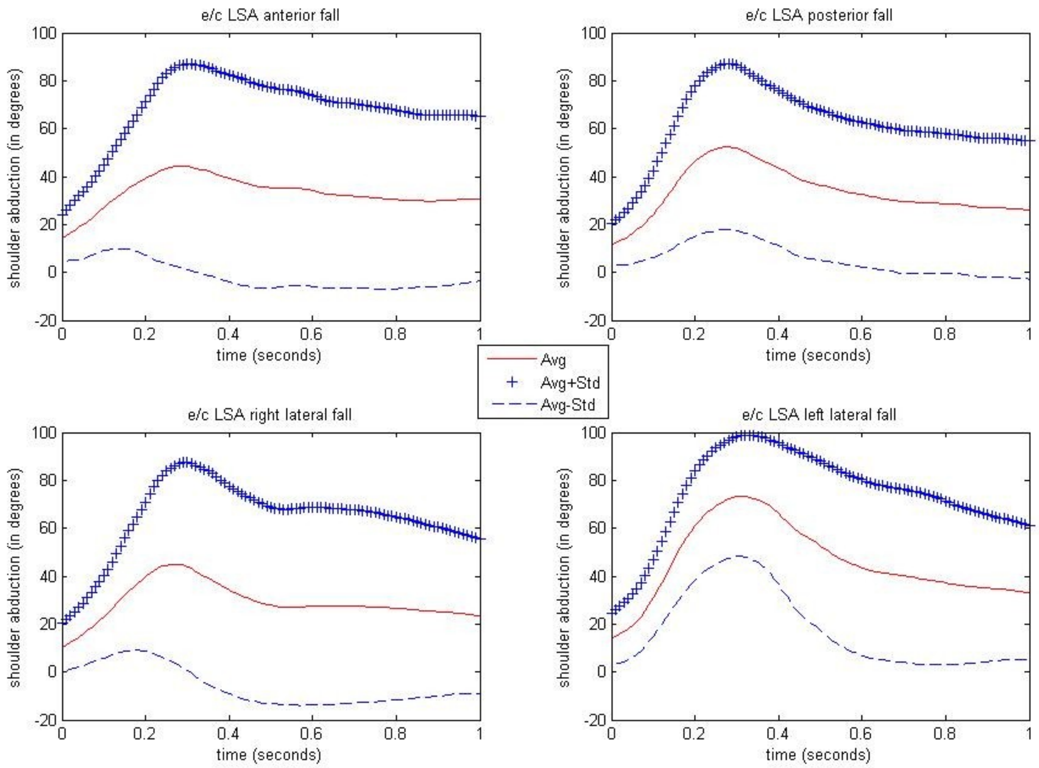
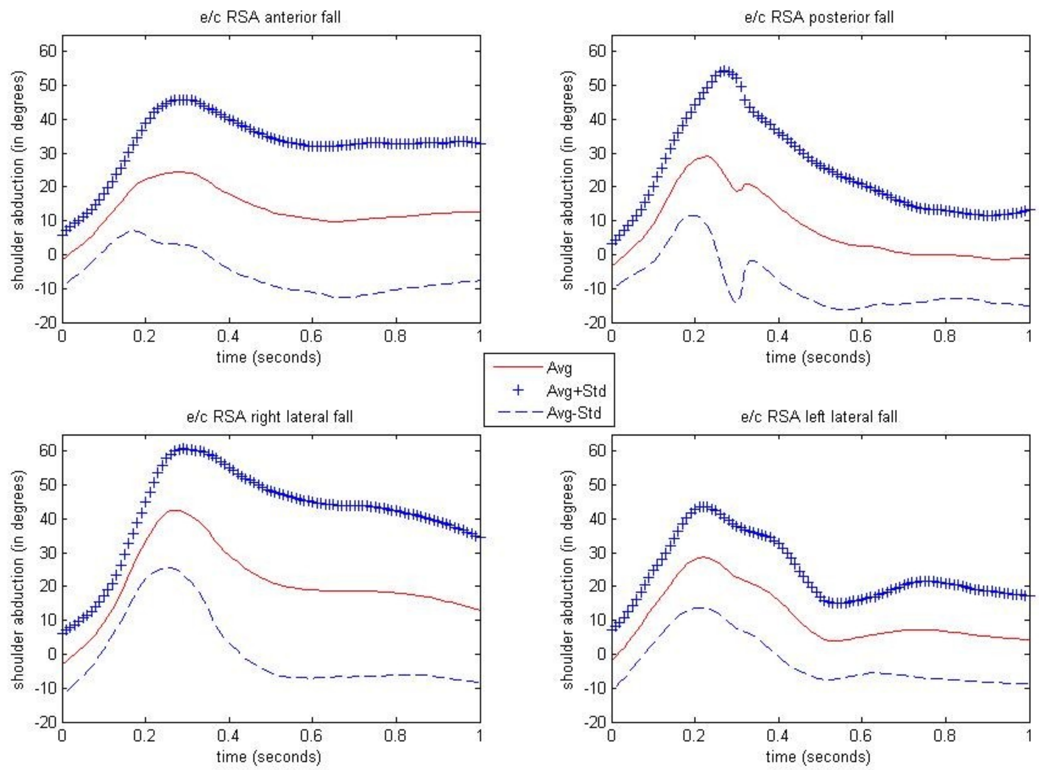
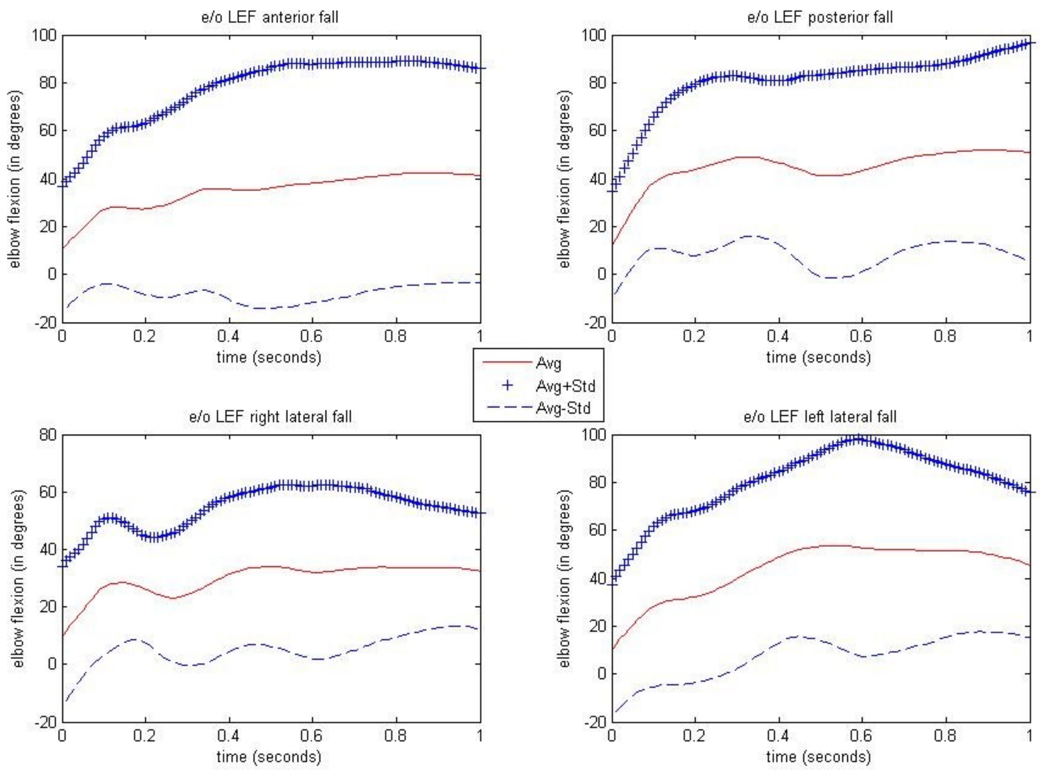


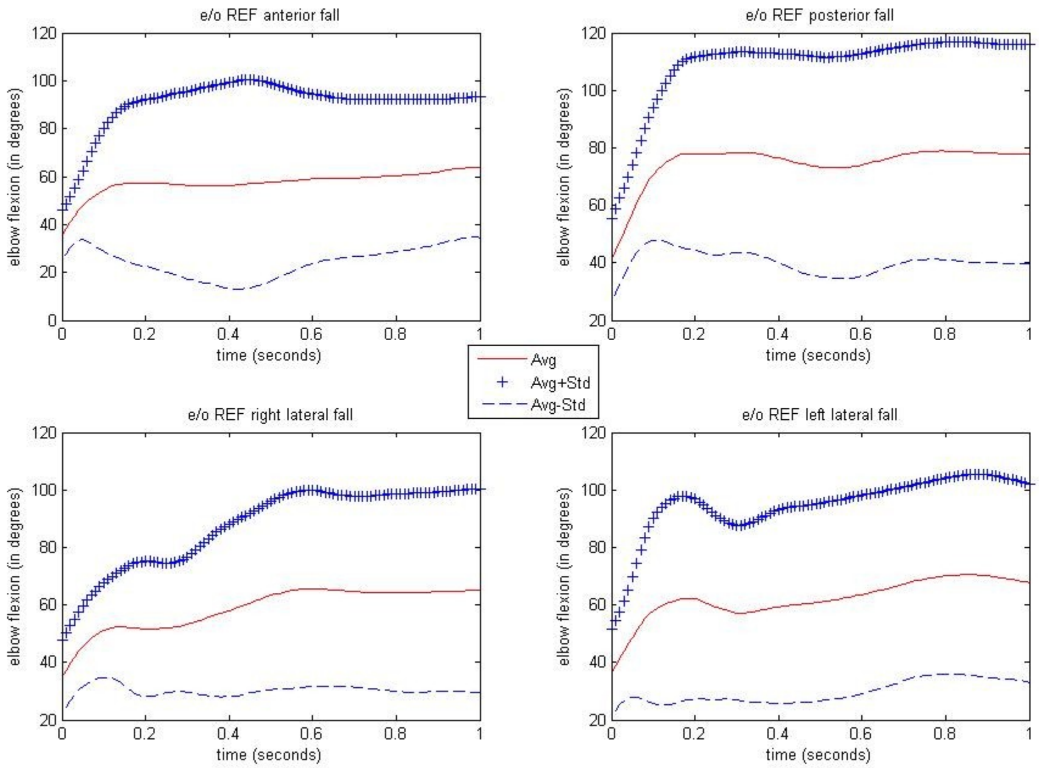
The above figure shows the average, average ± standard deviation for Left Shoulder Abduction (LSA) in the four different fall directions for eyes closed (e/c) subjects.



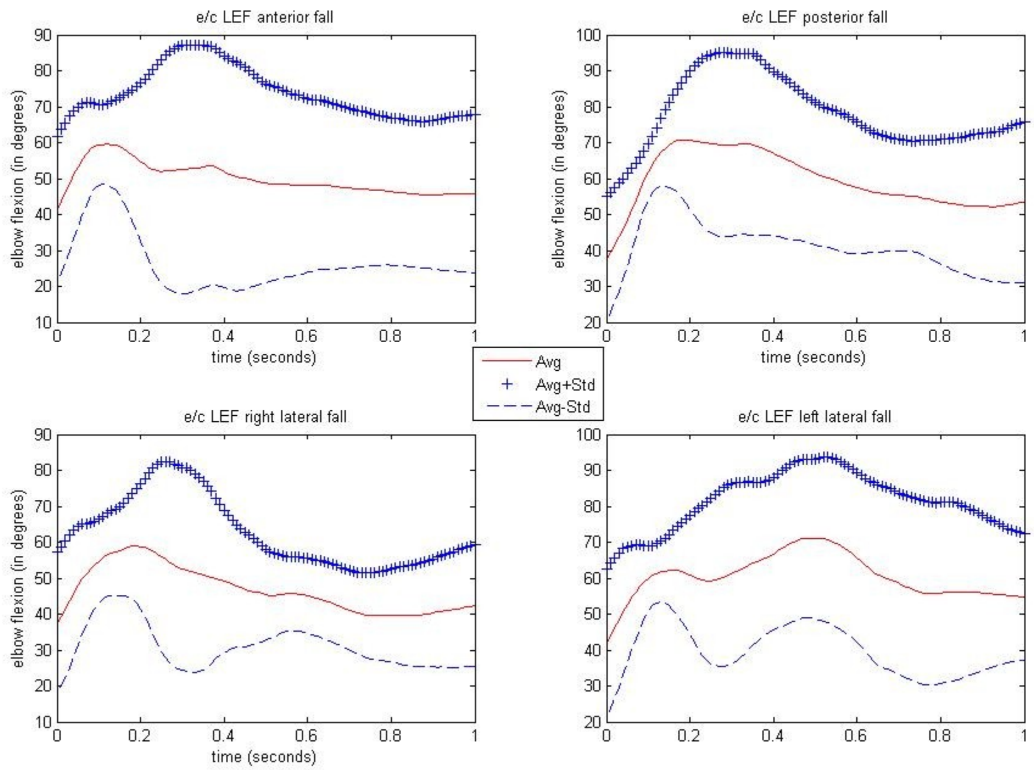
The above figure shows the average, average ± standard deviation for Right Shoulder Abduction (RSA) in the four different fall directions for eyes closed (e/c) subjects.



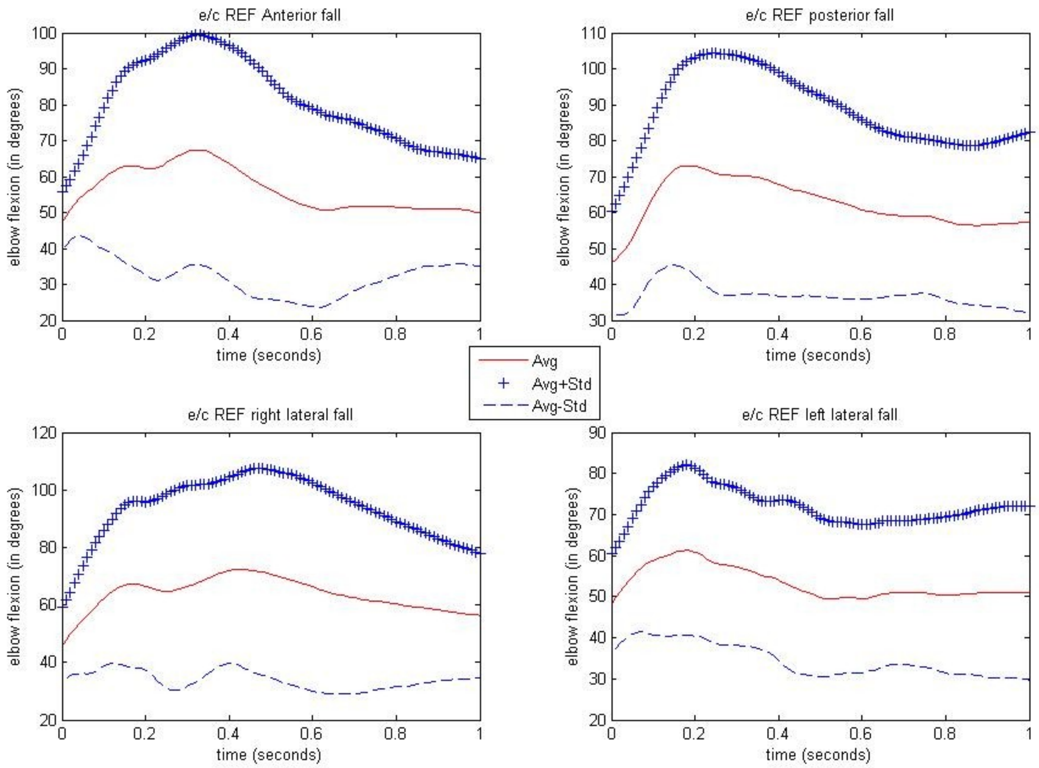
The above figure shows the average, average ± standard deviation for Left Elbow Flexion (LEF) in the four different fall directions for eyes open subjects.



The above figure shows the average, average ± standard deviation for Right Elbow Flexion (REF) in the four different fall directions for eyes open subjects.



The above figure shows the average, average ± standard deviation for Left Elbow Flexion (LEF) in the four different fall directions for eyes closed subjects.



The above figure shows the average, average ± standard deviation for Right Elbow Flexion (REF) in the four different fall directions for eyes closed subjects.

D Average subject peaks

Shoulder Rotation

Eyes open	Eyes (open=0,closed=1)	lsr for AF	lsrfor PF	lsr for RLF	lsr for LLF	rsr for AF	rsr for PF	rsr for RLF	rsr for LLF
e/o	0	49.0901	30.1523	20.9635	56.6232	58.1099	43.1487	74.4602	40.0036
e/o	0	46.7389	39.8149	26.3515	73.2837	33.6038	23.308	44.1927	29.2296
e/o	0	20.1359	18.9247	25.0611	37.8956	21.4813	29.7831	35.493	38.904
e/o	0	53.7434	19.9972	47.7889	60.9849	44.015	37.4826	48.1113	18.7563
e/o	0	19.194	25.5415	14.5866	40.0419	26.1024	18.2619	76.5234	21.4337
e/o	0	19.4758	22.9405	28.6218	21.3612	15.0129	11.5533	12.4545	27.8642
e/c	1	26.1044	21.644	46.4828	62.4428	18.4691	9.0482	50.5465	29.7804
e/c	1	14.1677	12.5467	16.2656	13.2841	11.5972	15.5624	7.9787	12.167
e/c	1	36.8694	23.0536	22.1536	22.1536	26.1419	20.1934	14.4823	28.935
e/c	1	23.9365	23.3647	11.6365	27.2946	11.5257	15.5141	21.0957	16.8464
e/c	1	17.7016	28.5931	44.6839	38.2962	19.9415	20.6221	20.1954	23.3756
e/c	1	38.6863	40.1839	25.8104	32.885	42.3397	33.4204	42.1108	30.42
Note:	All angles are in degrees.								

Shoulder Abduction

Subject #	Eyes (open=0,closed=1)	lsa for AF	lsa for PF	lsa for RLF	lsa for LLF	rsa for AF	rsa for PF	rsa for RLF	rsa for LLF
e/o	0	55.7171	64.5956	39.7455	76.8983	43.4851	37.8864	33.642	63.7077
e/o	0	80.0056	70.1097	47.8273	78.5122	32.1508	36.6336	39.8977	42.5364
e/o	0	42.4409	55.2511	60.441	74.2078	31.0242	41.6571	45.4814	58.1424
e/o	0	57.1976	54.967	50.8148	67.7106	43.2868	38.6631	35.6999	16.9418
e/o	0	17.8518	27.1291	23.4481	36.7256	19.3639	33.9397	78.2557	21.5802
e/o	0	13.8811	15.6743	11.9862	23.9765	24.4191	13.7452	19.6066	17.4656
e/c	1	96.8817	92.2305	108.1201	98.0666	64.2691	67.5366	88.6637	58.1733
e/c	1	14.1663	30.9963	11.8766	33.8711	23.1557	35.5342	30.6514	8.3761
e/c	1	19.6563	46.058	27.3551	27.3551	21.3823	46.2021	46.5539	46.5539
e/c	1	15.3267	14.1934	19.3633	63.8337	13.6809	26.3015	39.9264	15.6872
e/c	1	17.6161	45.3089	35.6362	55.9704	19.0588	43.4026	38.6756	37.4516
e/c	1	49.2545	38.7045	26.2332	53.5142	45.2788	49.2924	43.4267	36.6463
Note:	All angles are in degrees.								

Elbow Flexion

Subject #	Eyes (open=0,closed=1)	lef for AF	lef for PF	lef for RLF	lef for LLF	ref for AF	ref for PF	ref for RLF	ref for LLF
e/o	0	26.9958	54.2337	35.2139	53.0191	65.1687	81.0618	28.9275	73.7004
e/o	0	84.8667	66.6415	48.9989	87.9546	71.459	80.2051	69.4483	80.1688
e/o	0	20.3026	37.864	39.6934	35.616	15.6641	24.3756	12.0677	30.4559
e/o	0	28.5469	18.0464	16.1875	63.4595	48.8488	15.1476	47.5543	15.2929
e/o	0	83.2238	99.4904	60.1512	56.5978	62.1636	74.6134	90.4894	43.6661
e/o	0	32.4897	12.8429	36.7922	15.4053	34.6824	18.9631	22.842	22.3849
e/c	1	26.4216	41.9484	43.7171	41.9687	23.8834	21.1248	73.1189	12.7808
e/c	1	24.1638	35.5763	23.3362	17.422	30.5685	38.5874	28.8304	25.2379
e/c	1	47.4807	43.7701	34.8816	34.8816	38.8803	31.8414	42.4093	42.4093
e/c	1	24.4239	26.0182	28.1619	47.4291	26.4004	27.9098	37.6742	19.912
e/c	1	17.4868	23.8492	22.2002	14.5465	34.8974	16.4627	27.8848	17.9556
e/c	1	96.5816	84.3904	69.5588	93.234	88.3655	79.6664	87.6106	46.2056
Note:	All angles are in degrees.								