

Analysis of the effect of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living

by

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Authors Declaration

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

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Laurie Cathryn Hall

Abstract

Despite a large prevalence of rotator cuff impingements or tears in the elderly population, little research has focused on understanding how this population adapts to perform tasks of daily living. Past research has focused on the analysis of upper limb kinematics of young healthy individuals while performing these essential tasks (Magermans, 2004, Murray and Johnson., 2004). The purpose of this thesis was to identify kinematic and shoulder loading differences between elderly mobile individuals and elderly individuals with rotator cuff impingements during specific activities of daily living. Motion capture techniques were used in combination with the Shoulder Loading Analysis Modules (Dickerson, 2005, Dickerson *et al.*, 2007) to estimate thoracohumeral kinematics and calculate external joint moments. Two-tailed t-tests with injury status as the factor determined that differences in active range of motion in flexion/extension and humeral rotations existed between the two populations. Results of the ADL analysis showed that the impinged population tended to have decreased plane of elevation and humeral rotations during ADLs. Task was also a main factor for most variables examined. Perineal care, hair-combing and reaching tasks were the most demanding in terms of range of motion necessary to complete the task. The reaching tasks resulted in the highest shoulder moment. K-means clustering techniques proved to be unsuccessful in identifying different motion strategies between the two study groups. This investigation showed that developing adaptations for perineal care, hair-combing and reaching tasks should be considered a priority when working with patients with rotator cuff impingements, as these tasks demanded the largest ranges of motion as well as high shoulder moments.

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Table of Contents

Authors Declaration	ii
Abstract.....	iii
Acknowledgements.....	iv
Table of Contents	v
List of Tables	vii
List of Figures.....	viii
List of Equations.....	xi
1.0 Introduction	1
1.1 Role of the Rotator Cuff in Activities of Daily Living.....	1
1.2 Prevalence of Rotator Cuff Tears in the Elderly	2
1.3 Economic Importance of Evaluating the Effect of Rotator Cuff Impingements in the Elderly	3
1.4 Deficiency in Activities of Daily Living in the Upper Extremity	4
2.0 Purposes	6
3.0 Hypotheses	7
4.0 Literature Review.....	8
4.1 Methodologies of Existing Analyses of Upper Limb Kinematics of ADLs.....	8
4.2 Previous Investigations of Shoulder Range of Motion	10
4.3 Previous Investigations of ADLs in Mobile Populations.....	11
4.3.1 Previous Investigations of Feeding Tasks.....	11
4.3.2 Previous Investigations of Hygiene Tasks.....	13
4.4 Previous Investigations of the Effect of Rotator Cuff Impairments on Shoulder Kinematics	15
4.5 Impingement Tests	18
4.6 The Shoulder Loading Analysis Modules (SLAM)	21
5.0 Methodology.....	28
5.1 Subjects	30
5.2 Determining the Presence of Rotator Cuff Impingements	31
5.3 Motion Capture Protocol.....	32
5.4 Photographs or Video Recording	33
5.5 Experimental Set Up	34
5.6 Determining Active Range of Motion	35
5.7 Activities of Daily Living Testing Protocol	36
6.0 Data Analysis.....	39
6.1 Summary Statistics.....	41
6.1.1 Summary Statistics for ROMs.....	41
6.1.2 Summary Statistics for ADLs	42
6.2 Time Series Data	43
7.0 Results	44
7.1 Results of Range of Motion Tasks.....	44

7.2 Results of Activities of Daily Living Tasks.....	46
7.2.1 Results of the ANOVA Analysis	46
7.2.2 Results of the Time Series Data.	54
7.2.3 Results of Clustering Analysis	65
8.0 Discussion	72
8.1 Addressing Specific Aims and Hypothesis	72
8.2 Quantification of the Effect of Rotator Cuff Impingements on Range of Motion	74
8.3 Quantification of the Effect of Rotator Cuff Impingements on Activities of Daily	
Living	77
8.4 Limitations.....	83
8.5 Suggestions for Future Research.....	85
9.0 Conclusions.....	88
References.....	90
Appendix A: Information and Consent Form.....	99

List of Tables

Table 1: Mean subject characteristics by gender and participant group	30
Table 2: Marker placement	33
Table 3: Activity of daily living tasks	36
Table 4: Summary time series output data	41
Table 5: Summary of Angles of interest for each ROM task.....	42
Table 5: Range results for range of motion tasks	46
Table 6: Mean ranges of angle of elevation across tasks. Levels not separated by the same letter are significantly different.....	48
Table 7: Mean range of angle elevation interaction between injury status and task. Levels not separated by the same letter are significantly different.	49
Table 8: Mean velocity across tasks. Levels not separated by the same letter are significantly different.....	51
Table 9: Mean resultant external shoulder moments by task. Levels not separated by the same letter are significantly different.....	52
Table 10: Mean objective function by task.....	53

List of Figures

Figure 1: Shoulder anatomy and subacromial space (Austin Diagnostic Clinic).....	2
Figure2: Definitions of the local coordinate systems used in Magermans (2004 & 2005).....	13
Figure 3: the Hawkins impingement test.....	20
Figure 4: The painful arc impingement test.....	21
Figure 5: Flow of data through the SLAM mathematical model (Dickerson et al., 2007).....	23
Figure 6: Example of global torque output of the SLAM mathematical model (Dickerson, 2007).....	25
Figure 7: Example of muscle force outputs of the SLAM mathematical model (Dickerson, 2007).....	26
Figure 8: Outline of Experimental Procedure	29
Figure 9: Arrangement of subject, table and chair.....	34
Figure 10: Set up for the reaching tasks	38
Figure 11: Illustration of the y-z-y Euler rotation sequence (Magermans, 2005)	39
Figure 12: Results of maximum Euler angles during ROM tasks.....	45
Figure 13: Mean range of plane of elevation angles across task. Levels not separated by the same letter are significantly different.....	47
Figure 14: Mean range of angle of elevation interaction between injury status and task. Levels not separated by the same letter are significantly different.....	49
Figure 15: Mean range of humeral rotation across tasks. Levels not indentified by the same letter are significantly different.....	50
Figure 16: Mean velocity across tasks. Levels not separated by the same letter are significantly different.....	51
Figure 17: Mean resultant external shoulder moments interaction between task and injury status. Levels not separated by the same letter are significantly different.	53
Figure 18: Plane of elevation time series curves for the eating with a spoon task. Dotted lines represent standard deviations.	54
Figure 19: Angle of elevation time series curves for the eating with a spoon task. Dotted lines represent standard deviations.	55
Figure 20: Humeral rotations time series curves for the eating with a spoon task. Dotted lines represent standard deviations.	55
Figure 21: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.....	56
Figure 22: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.....	56
Figure 23: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.....	57
Figure 24: Plane of elevation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.	58
Figure 25: Angle of elevation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.	58

Figure 26: Humeral rotation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.	59
Figure 27: Plane of elevation time series curves for the perineal care task. Dotted lines represent standard deviations.....	60
Figure 28: Angle of elevation time series curves for the perineal care task. Dotted lines represent standard deviations.....	60
Figure 29: Humeral rotation time series curves for the perineal care task. Dotted lines represent standard deviations.....	61
Figure 30: Plane of elevation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.....	62
Figure 31: Angle of elevation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.....	62
Figure 32: Humeral rotation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.....	63
Figure 33: Plane of elevation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.	64
Figure 34: Angle of elevation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.	64
Figure 35: Humeral rotation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.	65
Figure 36: Results of clustering for eating with a spoon task Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingment population lies in the second sphere.....	66
Figure 37: Results of clustering for the hair combing task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingment population lies in the second sphere.....	67
Figure 38: Results of clustering for the washing with the axilla task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.	68
Figure 39: Results of clustering for the perineal care task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.	69
Figure 40: Results of clustering for the reaching above the shoulder task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingment population lies in the second sphere.....	70
Figure 41: Results of clustering for the scaled reaching above the shoulder task. Each sphere represents a grouping of participants based on the ranges of plane	

of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.71

List of Equations

Equation 1: Central Difference Equation.....40

1.0 Introduction

This introduction outlines the role of the rotator cuff in activities of daily living, the importance of evaluating rotator cuff impingements in an elderly population, and the current research documenting kinematics during the activities of daily living for the upper extremity.

1.1 Role of the Rotator Cuff in Activities of Daily Living

The shoulder is a complex mechanism consisting of four articulations: the glenohumeral, acromioclavicular, sternoclavicular and scapulothoracic joints. Although the shoulder has a large range of motion (ROM) and high postural flexibility, this comes with a compromise in stability (Steenbrink *et al.*, 2009; Veeger and Van der Helm, 2007). One suggested role of the rotator cuff muscles, which includes supraspinatus, infraspinatus, teres minor and subscapularis, is joint stabilization (Halder *et al.*, 2000, Soslowky *et al.*, 1997). In providing this stabilization, the muscles help to limit superior migration of the humeral head within the glenoid fossa. Weakness of these muscles can result in a superior translation of the humeral head, which may in turn cause tendon impingement in the subacromial space, which is located between the humeral head and the acromion (figure 1). This can result in damage or tearing of these rotator cuff tendons. Once damaged, the rotator cuff cannot provide the same stability to the shoulder joint (Hsu *et al.*, 1997, Steenbrink *et al.*, 2009). This can affect the ability to complete tasks of daily living. Some suggest that rotator cuff tears or impingements can exist without pain or effect on ability to perform tasks of daily living (Yamaguchi *et al.*, 2000). This implies that individuals with rotator cuff tears or impingements may adopt different motion

strategies in order to accomplish these tasks while maintaining a degree of shoulder stability.

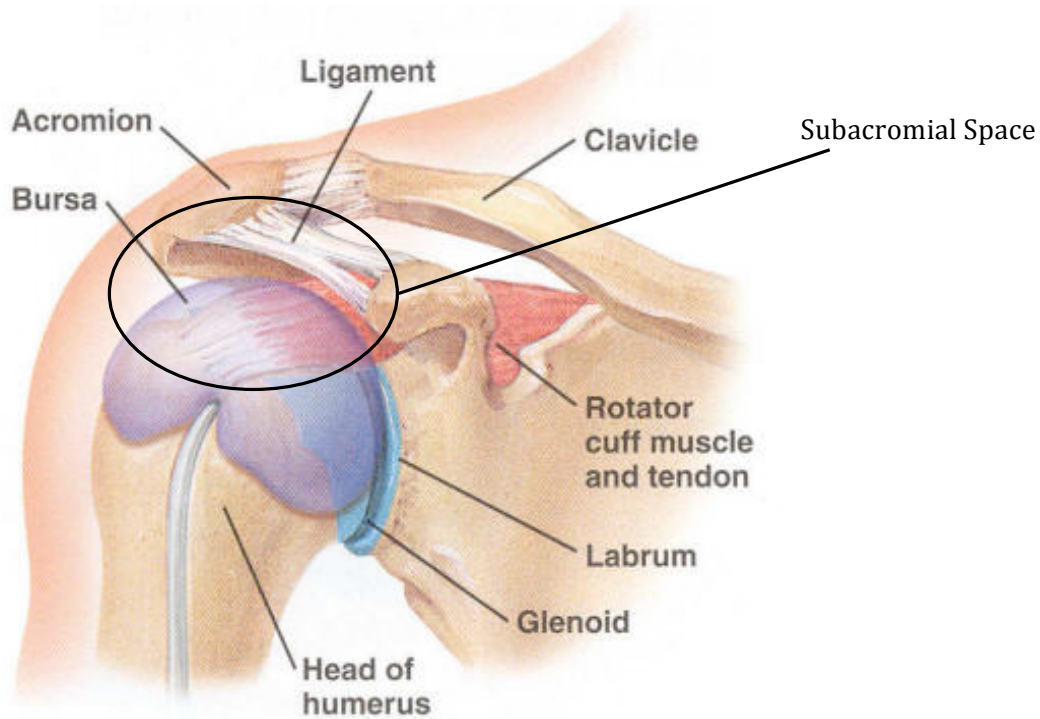


Figure 1: Shoulder anatomy and subacromial space (Austin Diagnostic Clinic)

1.2 Prevalence of Rotator Cuff Tears in the Elderly

The presence of rotator cuff disease is highly correlated with age (Yamaguchi *et al.*, 2006, Milgrom *et al.*, 1995). The average ages for unilateral and bilateral tears are 58.7 and 67.8 years, respectively. Sher *et al.* (1995) found that the prevalence of rotator cuff tears was significantly higher in asymptomatic people over 60 years of age than younger individuals with 28% of the over 60 group having full rotator cuff tears and 26% having partial tears while younger group, aged 19-39, showed no signs of full thickness rotator cuff tears and only 4% had partial thickness tears. This is supported by the research of Migrom *et al.* (1995) who determined that the prevalence of partial or full-thickness tears was over 50% of the dominant shoulders of individuals over the age of 70 and exceeded

80% in subjects over 80 years of age. Individuals that suffer with shoulder disorders have known increased functional dependency (van Schaardenburg *et al.*, 1994), and further that symptomatic rotator cuff tear patients have a decreased ability to perform activities of daily living (ADL) (Lin *et al.*, 2008). The decreased functionality at the shoulder means that the affected population likely needs assistance with ADLs and as a result, long term care.

1.3 Economic Importance of Evaluating the Effect of Rotator Cuff Impingements in the Elderly

Intensive long-term care is costly, to finances and quality of life, and at personal and societal levels. For instance, each resident of a long-term care facility is charged a minimum of \$1578.02 each month for basic accommodations (Ministry of Health and Long-Term Care). If one cannot afford the accommodations they can apply for a government subsidy. This translates into, in the worst case, a public economic burden and, in the best case, a financial burden for the family of the individual in need of long-term care. Despite a majority of the super-elderly (>80 years old) population with rotator cuff tears and the large economic burden, research studies regarding shoulder function in the elderly population are sparse. If it were possible to determine how those living with unrepaired rotator cuff tears or impingements manage to complete activities of daily living (or do not), then it may be possible to design environments or keep elderly with these types of injuries living independently and thus reduce the financial burden of long-term care. This could also help improve their quality of life as chronic musculoskeletal pain and decrease functionality has been linked with increased depression (Stubbs *et al.*, 2009).

1.4 Deficiency in Activities of Daily Living in the Upper Extremity

In order to live independently, one must be able to complete ADLs including feeding tasks, household tasks, such as putting away something on shoulder height shelf and hygiene tasks such as hair brushing, washing the axilla and perineal care, without assistance. Due to the large range of shoulder motion required by these tasks, they can be complicated or infeasible for those with rotator cuff tears or impingements. Despite the large prevalence of these shoulder ailments in an elderly population, there is limited research on the kinematics of the upper extremity of the elderly while performing ADLs.

Historically, most research on the kinematics of performing ADLs has focused on mobile, young populations with no shoulder impairments (Safae-Rad *et al.* 1990, Murray and Johnson, 2004, Magermans, 2004, van Andel *et al.*, 2007). Although this population can provide insight into some of the physical requirements of these daily tasks, they do not represent populations that are typically highly challenged by ADLs. Results are often reported in terms of maximal and minimal joint angles and mean joint angles throughout the task, but are unable to address the issue of adaptive strategies developed by individuals with disabilities to complete tasks.

Even fewer studies have attempted to address the issue of how daily tasks are accomplished by persons with rotator cuff impairments. Magermans (2004) attempted this through mathematical stimulation by using a musculoskeletal computational shoulder model to systematically limit the force producing capability of the 4 rotator cuff muscles. The kinematics of the upper extremity of an impaired population has not been collected directly *in vivo*, however. Further, Magermans (2004) used upper extremity position data

from mobile individuals as input to his modeling approach, which likely does not correspond to task performance by an injured or elderly population. This creates skepticism when applying the information gained from these simulations, as it is almost certainly not representative of the impaired population.

Limited studies have evaluated the glenohumeral joint contact forces of the upper extremity that are involved in daily tasks. Indeed, existing studies focused on cadaver approaches. Modeling techniques have yielded unreasonable joint contact forces in impaired populations and have been generally unsuccessful in determining changes in motor strategies between mobile and impaired groups even though it has been suggested that different motor strategies exist between these populations (Roy *et al.*, 2008).

Importantly, research in this area has yet to include elderly populations. This lack of information regarding the kinematic differences between participants with healthy and impaired rotator cuffs demonstrates that there is a need for a thorough investigation of shoulder kinematics and muscle activity during ADLs in an elderly population.

2.0 Purposes

The purposes of this thesis were to:

1. Identify kinematic differences between elderly individuals with and without symptomatic rotator cuff impingement during specific activities of daily living
2. Quantify external shoulder moments during these specific activities of daily living
3. Identify differences in shoulder range of motion between elderly individuals with and without rotator cuff impingement
4. Link these differences by describing mechanistic movement adaptations of the studied populations, if any exist

Knowledge of kinematic adaptations is critical for developing rehabilitation and living environments that consider both adaptive strategies and post-injury limitations in enabling the elderly to complete ADLs. The identification of the range of motion of the elderly with rotator cuff impingements could also aid in identifying possible design changes to environments. This in turn will serve to keep elderly populations (with and without rotator cuff impingements) highly active and independent as long as possible.

Quantifying shoulder physical loads will help determine what daily activities elderly with and without rotator cuff tears or impingements are capable of completing, as well as the relative demands of each ADL. This data could assist many future studies, including muscular fatigue evaluation in the elderly and an appropriate exposure level to apply in tribological wear testing of shoulder endoprostheses for arthritic treatment.

3.0 Hypotheses

Young populations with signs of rotator cuff impingement or tears have shown little differences in active shoulder range of motion capability in flexion and abduction (van Andel *et al.*, 2008, Baydar *et al.*, in press, Kilintberg *et al.*, 2008). However, differences in internal and external rotation ranges of motion are present in mobile and impaired populations (van Andel *et al.*, 2008, Senbursa *et al.*, 2007). It is therefore hypothesized that:

- Active range of motion will be reduced in the impaired elderly population when compared to the mobile elderly population in internal and external rotation only.

Literature suggests that different movement strategies may exist between subject groups (Roy *et al.*, 2008) in terms of both joint angles and muscle activation (Myers *et al.*, 2009).

The second hypothesis is therefore that:

- Different, identifiable, movement strategies will exist between the two study populations

Various tasks require different demands in terms of the range of motion necessary to complete them (Magermans, 2004). Knowing which tasks are most demanding will help to identify which need to be modified first. The third hypothesis is that:

- Different humeral ranges of motion will be required across different tasks

4.0 Literature Review

This section reviews the current literature pertinent to existing analyses of upper limb kinematics, previous investigations on ROM, previous investigations of ADLs in mobile populations, previous investigations of the effect of rotator cuff impairments on shoulder kinematics, descriptions of shoulder impairment tests and a brief review of The Shoulder Loading Analysis Modules (SLAM).

4.1 Methodologies of Existing Analyses of Upper Limb Kinematics of ADLs

Despite the importance of tasks of daily living, limited literature has focused on the kinematics of ADLs involving the upper limb (Buckley *et al.*, 1996). Generally, all existing quantitative upper limb kinematic studies on ADL performance and range of motion have used young, mobile populations. This section will outline the populations used in previous literature and demonstrate the need for more in-depth study of older populations with rotator cuff impingements. Comparisons of findings will be completed in sections 4.2 through 4.4.

More recent work has also investigated ADLs amongst healthy, younger populations. Murray and Johnson (2004) used a video based measurement system to study the upper limb during ADLs. This research examined the upper limb kinematics and dynamics of ten unimpaired males (average age 34.3 +/-11 years) while performing ten tasks of daily living including feeding, hygiene and everyday object tasks like answering the telephone or raising a block to shoulder height. Complex tasks, including perineal care, were omitted from this study.

Further information exists for female populations. Magermans (2004) monitored maximal joint angles of the upper extremity during ADLs in a young, mobile female population (average age 36.48 +/-11.8 years). Seven ROM tasks as well as five ADL tasks were analyzed for shoulder and elbow kinematics. Scapular lateral rotation, humeral rotation and humerus elevation levels have been reported for four ADLs performed by ten mobile subjects, including both males and females (van Andel *et al.*, 2008). There is a need to consider the kinematics of the upper limb during ADLs in an impaired population in order to determine if kinematic differences exist between mobile elderly and elderly with rotator cuff impingements.

Methods of comparing data across study groups has varied in the literature. Shoulder and elbow results are often presented in terms of maximum ranges of motion and maximum joint forces and moments (Safae-Rad *et al.*, 1990, Magermans, 2004, Murray and Johnson, 2004, van Andel *et al.*, 2008). In some studies, individual participants' angles, forces or moments were normalized to a percentage of task cycle and visually compared to one another to determine if kinematics were similar between participants (Murray and Johnson, 2004). Others normalized to percentage of task cycle for each individual then determined the mean kinematics of the subject pool for each task without making comparisons between subjects (Magermans, 2004, van Andel *et al.*, 2008). Although some speculation exists to suggest that different people may adapt different motion strategies, no analysis of the kinematic data was completed to determine if the motion patterns between subjects were statistically different. A method proposed by Park *et al.* (2005) suggests the use of a "joint contribution vector" (JCV) to quantitatively represent

a motion by accounting for the contributions of different joints to achieve a task goal. The JCV can be used with statistical clustering methods to determine if two motion techniques were different from each other. The study determined that this method was suitable for use in a one-handed load transfer task. Such a method is extendable in concept for the analysis of ADLs to determine if motion patterns between subjects and impairment groups differ. Although important foundational work has been done, it is also apparent that there is a need for continuing investigations into the kinematic of upper limbs during ADLs, especially in older or impaired populations.

4.2 Previous Investigations of Shoulder Range of Motion

Data exists on the active range of motion of healthy shoulders. Active range of motion in the shoulders of young mobile individuals has been documented by van Andel *et al.* (2008) who reported that axial humeral rotation had a total range of motion of 149°. Internal rotation and external rotations was reported to be 60 +/- 9° and -89 +/- 13° respectively. Maximal humeral elevation in anterior flexion and abduction were reported to be close with angles of 138 +/- 9° and 133 +/- 9°, respectively (van Andel *et al.*, 2008). Magermans (2005) used Euler angles of the humerus relative in to the torso to describe ranges of motion of the humerus in a healthy female population. Flexion/retroflexion had humeral elevation range of 181° with a mean forward flexion and retroflexion angles of elevation of 130.5 +/- 9° and 50.5 +/- 8.1° respectively. The range of abduction/adduction was similar to that of flexion/retroflexion with an overall range of 185.4° (131 +/- 10.3° abduction and 54.4 +/- 19.6° adduction). Humeral rotations range from 61.7 +/- 15.7°

internal rotation to $75.5 \pm 15.7^\circ$ external rotation, giving an overall humeral rotation range of 137.2° .

Rotator cuff impingements or various degrees of rotator cuff tears have been shown to have flexion and abduction ROMs similar to those of unimpaired shoulders. Active elevation has been shown to be $139.3 \pm 23.8^\circ$. Abduction angle were similar with a mean maximal elevation angle of 132.7 ± 31.6 (Baydar *et al.*, 2008). Baydar (2008) found external rotations of $59.5 \pm 16.1^\circ$. Internal rotations were measured by posterior anatomical segment reached by thumb and scored between 1 and 20 with 1 representing less than trochanter and 20 representing second thoracic vertebra, which is not helpful for comparison to other studies which measure internal rotation in degrees.

4.3 Previous Investigations of ADLs in Mobile Populations

Three important categories of daily living tasks have been examined on young, mobile populations. These include feeding, hygiene and lifting tasks.

4.3.1 Previous Investigations of Feeding Tasks

Eating is a task of daily living that is essential for independent living and has received the most attention in ADL literature (Safae-Rad *et al.*, 1990, Magermans, 2004, Murray and Johnson, 2004, van Andel *et al.*, 2008). An early study by Safae-Rad *et al.* (1990) focused on 3 feeding tasks and found that the shoulder joint rotations involved in these tasks had maximum values of 43.2° flexion from the coronal plane, 31.2° abduction from vertical and 23.4° of internal rotation. The arc of movements for these feeding tasks ranged from 24.4° - 28.3° shoulder flexion, 11.5° - 18.5° shoulder abduction and 12.0° -

18.2° internal rotation. Alternatively, feeding tasks have also been reported to have much smaller maximum values of joint movements, ranging from 6.82°-10.00° flexion, 8.04°-9.35° abduction and 7.64°-11.68° internal rotation (Murray & Johnson, 2004). A similar feeding task showed comparable humeral evaluation angles to Murray & Johnson (2004)(van Andel *et al.*, 2008) but humeral rotations were reported in an alternative coordinate system, making it difficult to compare results. Magermans (2004) reported feeding task ROMs in Euler angles of the humerus relative to the scapula in a y-z-y rotation as defined by van der Helm and Pronk (1995) (figure 2) and reported maximal plane of elevation (first rotation) of 60°, mean maximal elevation angle (second rotation) as 73.5° and axial rotation (third rotation) as -49.3°. From this study it was concluded that an eating task does not require the full ROM of the shoulder and is instead limited by the elbow joint. Investigation into how this task differs in an elderly population has yet to be examined.

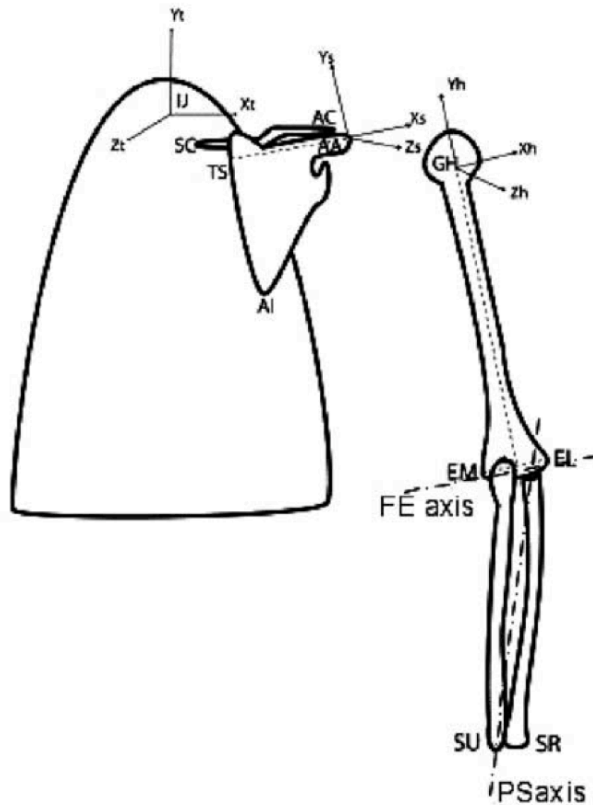


Figure2: Definitions of the local coordinate systems used in Magermans (2004 & 2005)

4.3.2 Previous Investigations of Hygiene Tasks

The ability to live independently is dependent on the ability to complete tasks related to personal care such as washing, hair combing or perineal care.

Washing the axilla is a task that could present some ROM challenges for the washing arm as it has been shown to involve increased humeral rotation when compared to other ADLs (Murray & Johnson, 2004, van Andel *et al.*, 2008). Internal rotation has been reported to be as much as 12.96° from anatomical position (Murray & Johnson, 2004). Magermans (2004) reported plane of elevation, angle of elevation and axial rotations of 99.6° , 10.8° and -15.2° respectively. The plane of elevation is located at a much larger

angle when compared to other ADLs indicating that the ROM required for this task could be challenging.

Hair combing or reaching to the side and back of the head is another task that has been common among studies (Magermans, 2004, Murray & Johnson, 2004, van Andel *et al.*, 2008) with maximal joint angles reaching 38.08° flexion, 13.88° abduction and 52.48° internal rotation. It is possible that several techniques to accomplish this task exist, especially at the wrist and elbow (van Andel *et al.*, 2008). Magermans (2004) reported plane of elevation, angle of elevation and axial rotations of 58.5°, 89.8° and -70.2° respectively for this task and discusses that although this task requires large amounts of humeral elevation, internal rotation may be the limiting factor in ones ability to comb their hair.

Studies that examine the ROM involved in perineal care are limited. Plane of elevation, elevation angle and axial rotation angles were reported as -67.2°, 35.0° and 105.4°.

Perineal care is a task that requires a large amount of internal rotation and extension of the humerus (Magermans, 2004), which differs from most of the other ADLs that require external rotation and flexion of the humerus. This is a clinically relevant finding in that rehabilitation that focuses on external rotation could compromise the patient's ability to perform internal rotation. This affects their ability to perform personal care tasks and therefore also their ability to live independently (van Andel *et al.*, 2008).

4.4 Previous Investigations of the Effect of Rotator Cuff Impairments on Shoulder Kinematics

Little research has been done to assess the kinematics of the upper limb in patients with unrepaired rotator cuff tears or impingements. Existing studies have concentrated mostly on the superior migration of the humeral head within the glenoid fossa with increased abduction rather than the gross kinematics of the arm throughout the task (Hallström *et al.*, 2006, Yamaguchi *et al.*, 2000). However, some studies have examined movement strategies by looking at muscle activations, glenohumeral joint forces or by using models to determine how the rotator cuff muscles contribute to motions involved in ADLs.

Few studies examine muscle activation or movement strategies in patients with rotator cuff impingements. There are documented differences in moving strategies in impingement patients when compared to a control population, but not all impaired patients present the same abnormal motor strategies (Roy *et al.*, 2008). It was suggested that impingement patients tend to move their trunk more than patients with mobile shoulders (Roy *et al.*, 2008). However there is some discrepancy in terms of muscle activation in that Roy *et al.* (2008) found no significant change in EMG activity while Myers *et al.* (2009) found that participants with impingements compensated with increased middle deltoid activation at the initiation of elevation rather than relying on the impinged supraspinatus to initiate the movement.

Our knowledge of bone-on-bone forces during activities of daily living is similarly limited. Research in this area has mostly focused on cadaveric studies. One such study used a dynamic shoulder testing apparatus to simulate abduction in the scapular plane by

applying equal forces to the rotator cuff and deltoid tendons at a rate of 20 N/s (Parsons *et al.*, 2002). One cadaver arm was used to collect five different sets of joint contact forces: intact rotator cuff, partial supraspinatus tear (disruption of the anterior portion of the tendon, full supraspinatus tears (complete disruption of the tendon), supraspinatus/infraspinatus tear (complete disruption of the supraspinatus tendon and 1.5 cm disruption into the infraspinatus tendon) and global tear (advancement of tear 1.5 cm in the subscapularis tendon) (Parsons *et al.*, 2002). No force was applied to tendons that were completely torn. Joint contact forces were measured directly using a 6-degree of freedom force-moment transducer. Differences in bone-on-bone force did not exist between the intact, incomplete or full supraspinatus tear conditions, with forces ranging in magnitude from 296-337N. Both the supraspinatus/infraspinatus tear and the global tear yielded results significantly lower than the other groups with magnitudes of 149 and 126N respectively.

As a continuation of this research, four simulated muscle strategies were examined to determine if the ratio between the forces applied by the deltoid and those applied by the supraspinatus tendon affected the glenohumeral joint contact forces (Apreleva *et al.*, 2000). The four strategies were; equal force applied to each tendon, supraspinatus dominant condition (2:3 ratio of applied forces between the deltoid and supraspinatus), deltoid dominant condition (3:2 ratio of applied force between the deltoid and supraspinatus) and supraspinatus paralysis (5N force applied to supraspinatus tendon throughout motion to maintain minimal tension in the cable). Different muscle strategies produced slightly different glenohumeral joint contact forces during abduction with a

range from 365N for a supraspinatus dominant technique to 279N for a shoulder with supraspinatus paralysis (Apreleva *et al.*, 2000). This suggests that there may be different muscle strategies may occur to maintain suitable joint contact forces.

Although these studies provide a rough estimate of joint contact forces, the forces applied by the muscles or the muscle strategies are not necessarily the same as those seen in a live participant. These results are within the same ranges of glenohumeral joint contact forces for unimpaired shoulders determined from modeling techniques (Magermans, 2004). Modeling based results for groups with impaired rotator cuffs yield much higher glenohumeral forces, some reaching as high as 1800N for some ADLs (Magermans, 2004)

Magermans (2004) used kinematic data from mobile participants performing ADLs as input into a finite element musculoskeletal model (van der Helm, 1994) to determine the role of the rotator cuff in ADLs. Locations and magnitudes of joint contact forces were reported for all successful simulations. The results indicated that the function of the rotator cuff is dependent on the position of the humerus. It is hypothesized that these muscles act as stabilizers during higher extension or adduction angles and they act as prime movers during higher humeral elevation angles. Indeed, tasks that required over 90° of elevation are often dysfunctional with the absence of rotator cuff muscles. When rotator cuff force was limited to 10% of maximum force, most simulations were successful (only 26% of simulations were unsuccessful) indicating that other muscles could compensate for the decreased rotator cuff force. However, this study was limited

in that not all simulations were able to find a solution. Seventy-seven percent of simulations without rotator cuff muscles were unsuccessful because the model could not meet moment or stability constraints indicating the rotator cuff plays a critical role in the performance of most tasks. This does not necessarily indicate that people are incapable of performing the task without using the rotator cuff muscles. The kinematic data used as input was from a mobile population that may not move in the same fashion as an impaired population that has limited rotator cuff function. Perhaps if the kinematic data from an impaired population were to be used as model input, the model could find solutions that meet all the model constraints even when the rotator cuff muscles are eliminated from the model. More research into how an impaired population completes ADLs is required in order to determine the extent of their compensation techniques.

4.5 Impingement Tests

Several diagnostic tests are available to test for the presence of a rotator cuff impingements, which can vary in severity. The most popular of which are the Hawkins test and the painful arc test.

The Hawkins test was developed as a modification of the Neer impingement test, which was preformed by having the patient flex their shoulder and internally rotate. The Hawkins test is very similar in that the shoulder is flexed to 90° and internally rotated so that the thumb is pointing toward the ground (Hawkins & Kennedy, 1980). From this position the examiner forcibly continues the internal rotation of the arm, which is not done in the Neer test (figure 3). This positions the greater tuberosity under the

coracoacromial ligament (Hallström & Kärrholm, 2006). If any superior migration of the humeral head occurs this will cause impingement of the rotator cuff tendons (particularly supraspinatus) between the acromion or the coracoacromial ligament. Pain (as determined by the patient) in this position corresponds to a positive impingement result. The Hawkins impingement test has been shown to produce more lateral and superior translation of the humeral head in patients with impingements than in those without. The Neer test showed no kinematic abnormalities, indicating that the Hawkins test is a more sensitive diagnostic tool than the Neer test (Hallström & Kärrholm, 2006). The Hawkins test has reported to have sensitivity ranging from 88% to 92.1% (MacDonald *et al.*, 2000, Çalis *et al.*, 2000) and high negative predictive values ranging from 55.7 to 90% (MacDonald *et al.*, 2000). However, the Hawkins test has been reported to have low specificity with reports ranging from 23.0 to 68.7% with most values in the high end of that range (Çalis *et al.*, 2000, MacDonald *et al.*, 2000, Park *et al.*, 2005). Positive predictive values ranged from 52.6-79.7% (Çalis *et al.*, 2000, MacDonald *et al.*, 2000, Park *et al.*, 2005).



Figure 3: the Hawkins impingement test

The painful arc test is another indicator of rotator cuff impingement. In this test, the patient abducts their arm (figure 4). Pain occurring between 60 and 120° of arm abduction indicates a subacromial disorder while pain above 120° indicates a disorder of the acromioclavicular joint (Kessel & Watson, 1977). This test has been shown to have high specificity (80.5-81.1%) and positive predictive values (80.5-88.2%) but lower sensitivity and negative predictive values ranging from 37.5-73.5% and 38.7-61.5% respectively (Park *et al.*, 2005, Çalis *et al.*, 2000). This test is rarely positive for shoulder disorders other than rotator cuff impingement (Çalis *et al.*, 2000)

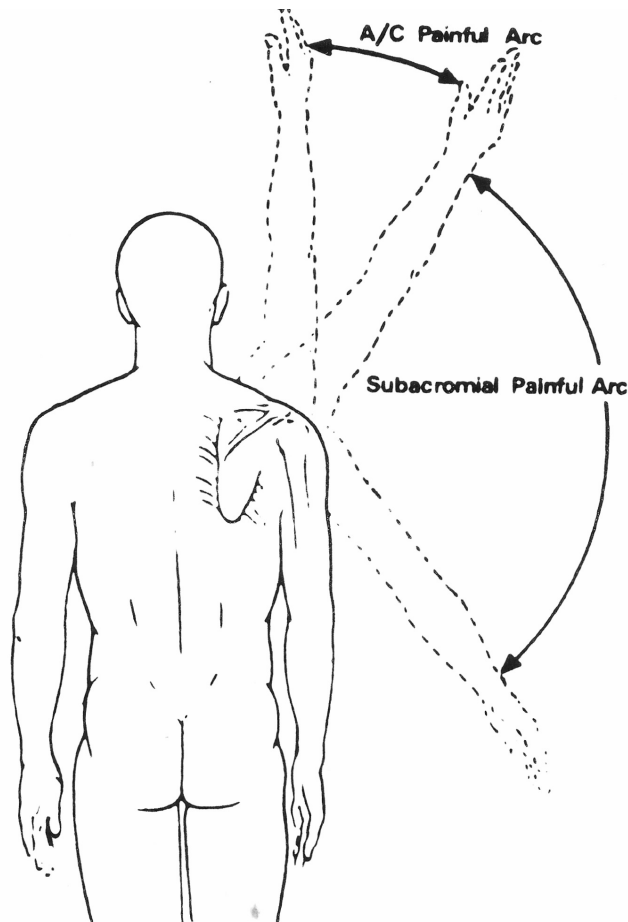


Figure 4: The painful arc impingement test

It has been suggested that a combination of tests may be most useful in determining if rotator cuff impingement exists. Specifically, the combination of the Hawkins and painful arc yielded the best post test probability (95%) for any degree of impingement syndrome (Park *et al.*, 2005). This combination includes a test with high sensitivity (the Hawkins test) and one with high specificity (the painful arc test).

4.6 The Shoulder Loading Analysis Modules (SLAM)

Directly measuring muscle activity of the rotator cuff requires the use of invasive techniques such as indwelling electromyography that come with risks of complications such as infection, along with high specificity. These risks may have little effect on a

young, mobile population but could have pronounced effects in an elderly population. Thus, it is an unsuitable technique for use in a elderly population. Furthermore, use of surface electromyography in an elderly population could be complicated by skin movement and associated landmark identification difficulty. Since it is important to understand how shoulder muscles are contributing during ADLs, the Shoulder Loading Analysis Modules (SLAM) software (Dickerson, 2005; Dickerson et al., 2007, 2008) will be used to evaluate several shoulder-loading parameters.

The SLAM software is a collection of computerized models intended to generate physiologically accurate predictions while including the dynamics of tasks. The model is a unilateral, mathematical representation of the right upper limb. It consists of 3 major components: a musculoskeletal geometric model, an external dynamic shoulder torque model and an internal muscle force prediction model. The outputs of the geometric model and external dynamic shoulder torque model are used as inputs to the internal muscle force prediction model (Figure 5).

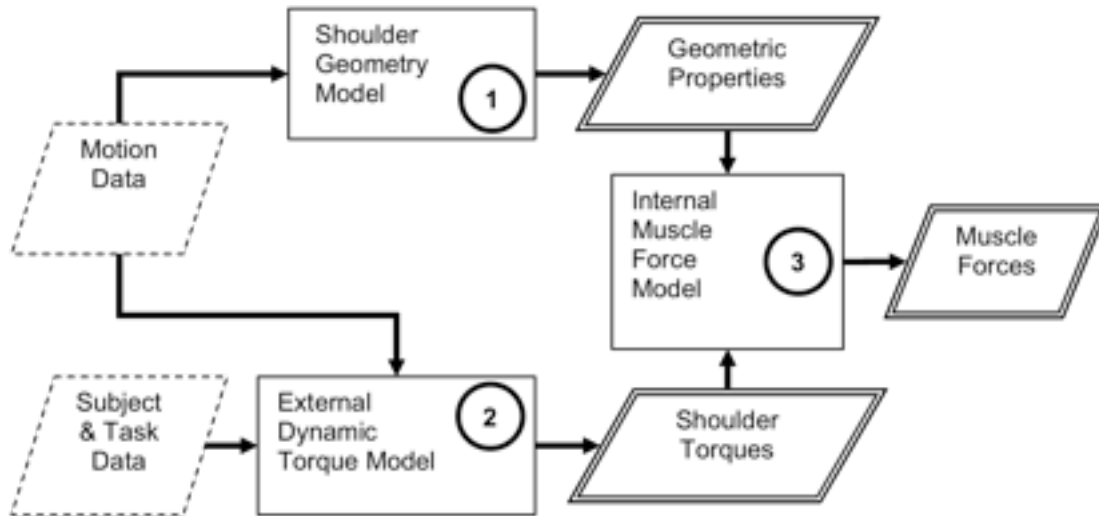


Figure 5: Flow of data through the SLAM mathematical model (Dickerson et al., 2007)

The purpose of the geometric model is to convert motion capture data, into the orientations of the upper limb segments and torso, along with musculoskeletal element definition. Bones lengths were derived from work done by Högfors *et al.* (1987) with the exception of the torso length, which is defined as 70% of the length between the first thoracic and fifth lumbar vertebrae, which are obtained from the motion tracking data. This model considers 23 muscles of the upper limb and trunk, nine of which are represented by multiple lines of action. In general, muscles are defined as a 3-dimensional line between the origin and insertion of the muscle, however some shoulder muscles pass around orthopedic obstructions. These muscle paths are altered using spherical or cylindrical geodesic wrapping techniques (Charlton & Johnson, 2001).

The external dynamic shoulder torque model is an inverse dynamic model that calculates dynamic torques and forces throughout a motion trial. The inputs required are motion

data, participant mass, and forces and weights acting at the hand. The upper limb is modeled as three segments (hand, forearm and upper arm), with each joint connected by a spherical joint. Individual segment masses and moments of inertia are calculated using regression equations (Zatsiorsky *et al.*, 1993), while joint centers and segment centers of mass are calculated based on work by Clauser *et al.* (1969). All motion data is smoothed with a 2nd order, dual-pass Butterworth low pass filter set at 6Hz. Velocity and accelerations of segments were calculated by numerical differentiation. Joint forces and moments are calculated by enforcing dynamic equilibrium in accordance with Newton's Laws of Motion.

The muscle force prediction model uses the outputs of the external dynamic shoulder torque and the geometric models as inputs to determine a unique solution for the forces of the shoulder muscles. Since the shoulder is an indeterminate system, this model relies on a numeric optimization technique in order to achieve a unique solution. In order to do this several types of constraints are considered. The first type are mechanical equilibrium constraints, which states that the sum of the muscle forces acting on a segment plus the contact forces at both the proximal and distal joints of that segment is equal to the sum of the external forces on the segment. Secondly, the magnitude of muscle forces is limited in that all forces are required to be tension forces with a maximum force assumed to be proportional to the cross sectional area of the muscle. A glenohumeral contact force is constrained to remain within ranges that do not cause glenohumeral dislocation (Lippitt & Matsen, 1993). Finally, an objective function of minimizing the sum of the cubed muscle stresses is used to determine a unique solution.

The SLAM software was particularly useful for this study as it provided graphical representations of the motion as well as time-dependent values of forces within each joint due to external forces (Figure 6) and time-dependent values for muscle forces (Figure 7) represented in both an absolute and percentage of predicted maximum force form. All outputs are presented in a global coordinate system, but can be represented in local systems as well.

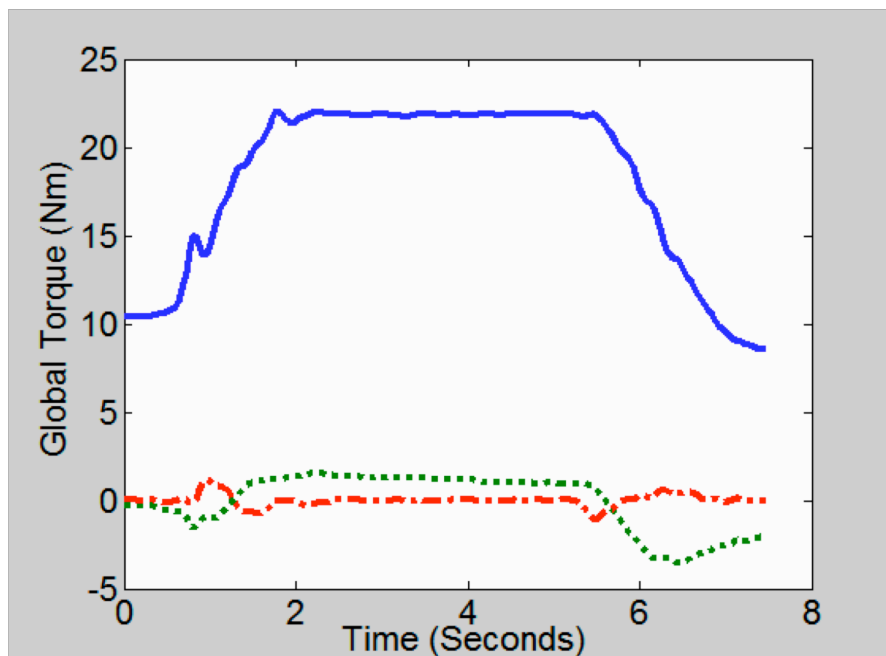


Figure 6: Example of global torque output of the SLAM mathematical model (Dickerson, 2007)

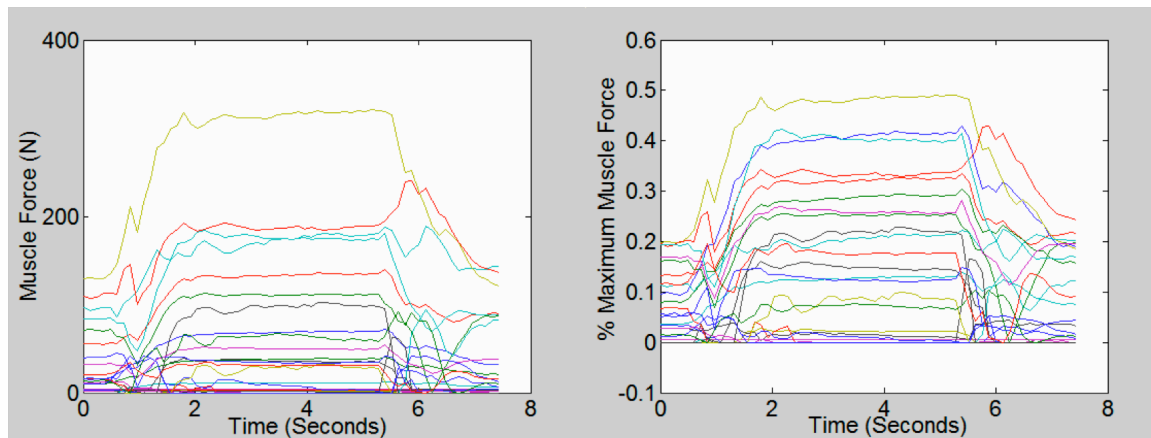


Figure 7: Example of muscle force outputs of the SLAM mathematical model (Dickerson, 2007)

The ability of this model to predict muscle forces that emulate electromyographic data in load transfer tasks has been established (Dickerson *et al.*, 2008). The software's prediction of muscle activation was very similar to the activation measured with electromyography, particularly for the prime movers. Two task types were analyzed, static holds and dynamic reaches. During static holds the muscle force predictions showed positive correlations with EMG. In the dynamic reach tasks, the software consistently predicted inactivity of muscles and yielded high concordance ratios for all primary contributors to the load transfer tasks.

An analysis of the ability of the SLAM software to predict moment arms for the rotator cuff muscles during elevation in the scapular plane has also been completed (Gatti *et al.*, 2007). The moment arms calculated by the SLAM software were compared to seven experimental studies. It was determined that the model predicted moment arms in the experimental data range for nearly all postures, partially confirming the geometric validity of the model across potential arm postures.

4.7 Overall Context of This Thesis Within the Literature

The kinematics and motion strategies of the upper limb in the performance of ADLs have received limited attention in research. Although some studies have examined basic kinematics of the upper limb during ADLs in young, healthy populations, limited knowledge exists as to how kinematics differ in populations with rotator cuff impingements. There is a need to expand this research into elderly populations as they are more likely to struggle with shoulder ailments and the performance of ADL tasks. Further studies on this particular population could help to identify motion strategies that could be used in a clinical environment to help keep aging individuals as mobile and independent as possible.

5.0 Methodology

The study was performed at three retirement facilities that are all part of the Oakwood Retirement Communities (Kitchener, Ontario). These locations included The Village of Winston Park, The Village of Wentworth Heights and The Village of Riverside Glen. At each facility, a motion capture system was set up in a secure locked room. The entire experimental procedure took approximately 1 hour per participant. Figure 8 summarizes the major steps of the experimental procedure.

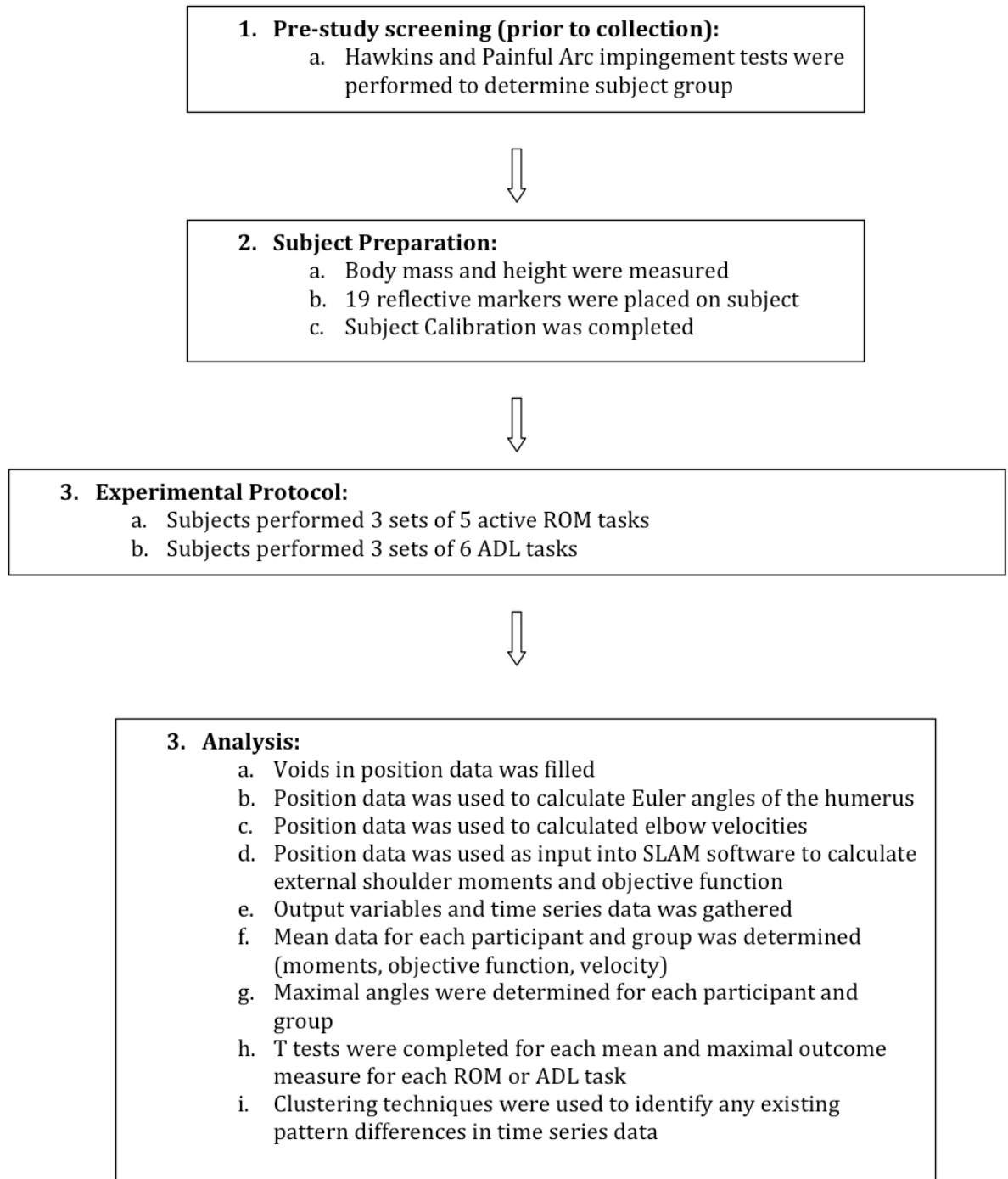


Figure 8: Outline of Experimental Procedure

5.1 Subjects

Two subject groups were examined in this study: 1) an uninjured elderly population and 2) an injured elderly population.

Twenty-three right hand dominant participants were recruited from an elderly population living in a network of Ontario retirement homes, and ranged in age from 66-93 years.

Thirteen of these subjects (nine females and four males) represented an asymptomatic elderly population. The participants in this group exhibited no signs of rotator cuff tears or impingements as determined by both the Hawkins and painful arc tests and had no history of shoulder pain or injury in the past six months. This was determined by asking them “Have you had any shoulder pain or injury within the past six months?”. The remaining ten subjects tested positive for rotator cuff impingements. This group included eight women and two males. The mean height weight and age of all participants are documented in Table 1.

Table 1: Mean subject characteristics by gender and participant group

Participant Group	Gender	Number of participants	Height (m)	Weight (kg)	Age(years)
Healthy	Females	9	1.55 +/- 0.15	72.0 +/- 6.1	82 +/- 2
	Males	4	1.72 +/- 0.04	72.0 +/- 8.2	87 +/- 7
Impingement	Females	8	1.59 +/- 0.07	58.4 +/- 18.4	83 +/- 8
	Males	2	1.72 +/- 0.09	71.9 +/- 4.2	81 +/- 12
All participants		23	1.61 +/- 0.13	67.3 +/- 13.2	83 +/- 6

Exclusion criteria included

- Upper limb or back injury (excluding rotator cuff impingements) within the past six months
- Diagnosed cognitive impairments (Alzheimer's disease or dementia)

Participants were recruited through posters and information sessions at the facilities. The purpose, requirements and possible benefits of the study were presented to the residents of the retirement home in order to increase interest in participating.

Prior to beginning data collection, the participants had the study purpose, methods, potential risks, and benefits explained to them. A consent form was signed prior to any data collection. Participants were made aware that they could withdraw from the study at any time. A feedback letter including researcher contact information was provided to the participant (appendix A).

5.2 Determining the Presence of Rotator Cuff Impingements

A screening process occurred in the days prior to data collection to determine if potential participants were symptomatic for rotator cuff impingements. A participant was considered symptomatic for rotator cuff impingement if they tested positive in both the Hawkins and painful arc tests. First, the painful arc test was performed. The participant was asked to slowly abduct their arm and to report if any portion of the abduction is painful. If pain was reported between 60-120°, then the test was considered positive for impingement. Upon completion of the painful arc test, the Hawkins test was performed. The participant was asked to flex their arm to 90° and then the arm was medially rotated

to the end range of motion. If the patient considered this painful, the test was considered positive for impingement.

5.3 Motion Capture Protocol

The kinematics of all trials were recorded using a Vicon MX20+ motion tracking system consisting of 7 cameras in combination with 19 reflective markers to record the kinematic data of each trial. All data was collected and processed using Vicon 1.2 software.

Marker locations are summarized in Table 1. These locations were chosen to correspond with a template compatible with the SLAM software (Dickerson, 2005; Dickerson et al., 2007), and used extensively in the past to capture upper limb movements (Brookham *et al.*, 2008). Seven light emitting diode cameras (2.0MP) were placed around the collection space. Cameras were placed to ensure that the collection area of the cameras encompassed the entire volume in which the subject was moving. Three markers per limb segment must be visible for each frame of data in order to define segmental orientation and position. Before the subject arrived, the capture volume was calibrated and the origin of the collection space was set behind the rear right side of the participant's chair. Upon arrival of the participant, all markers were placed on the landmarks provided in table 2. The participant was then asked to abduct their right arm to approximately 45°. A short subject calibration capture trial was taken in order to scale a pre-made template to the participant. During this trial, all markers on the participant were visible. During collection, markers were tracked and their spatial locations were recorded at a sampling rate of 50 Hz.

Table 2: Marker placement

Marker	Location
1	5th metacarpal phalangeal joint
2	2nd metacarpal phalangeal joint
3	ulnar styloid
4	radial styloid
5	lateral epicondyle
6	medial epicondyle
7	acromion
8	C7
9	L5
10	right posterior superior iliac spine
11	left posterior superior iliac spine
12	suprasternal notch
13	xyphoid process
14	arm cluster I
15	arm cluster II
16	arm cluster III
17	forearm cluster I
18	forearm cluster II
19	forearm cluster III

Note: All markers were placed on the right side of the body with arm cluster I, II and III forming a triangle on the arm and similarly forearm cluster I, II and III forming a triangle on the forearm.

5.4 Photographs or Video Recording

If the participant gave consent, photographs or video were taken during the study session.

Such media allows the researchers to recall how a task was performed as well as to verifying movement data. Photographs or video can be very useful in teaching and presenting the study in a scientific paper or presentation. All photographs or video were focused on the participant's torso and upper limb and were altered to conceal the identity of the participant.

5.5 Experimental Set Up

A chair with a height of 43 cm that allowed for the C7 and lumbar markers to be seen was placed behind a table that was 66 cm tall. The table had a start position marker pasted on it. The participant was allowed to adjust the distance between the chair and the table to allow them to move as normally as possible. This arrangement is displayed in figure 9 below.



Figure 9: Arrangement of subject, table and chair

5.6 Determining Active Range of Motion

Five active range of motion (ROM) tasks were performed three times by the participants. All trials, including repeats, were performed in a completely randomized order. Angles were derived from the position data captured using the Vicon motion capture system. The ROM tasks were as follow:

i) Forward flexion range of motion task

While seated, the participant was asked to flex their shoulder forward as far as possible.

ii) Backwards extension range of motion task

While seated, the participant was asked to extend their shoulder backwards in the sagittal plane as far as possible.

iii) Abduction range of motion task

While seated, the participant was asked to abduct their shoulder in the coronal plane as far as possible.

iv) Internal rotation range of motion task

While seated, the participant abducted their shoulder to 45° in the coronal plane while flexing their elbow to 90°, with their palm facing forward. The participant was then asked to rotate their arm as far across the front of their body as possible, while maintaining the abduction and elbow flexion angles.

v) External rotation range of motion task

While seated, the participant abducted their shoulder to 45° in the coronal plane while flexing their elbow to 90°, with their palm facing forward. The participant was then

asked to rotate their arm as far behind their body as possible, while maintaining the abduction and elbow flexion angles.

5.7 Activities of Daily Living Testing Protocol

Participants performed six tasks designed to emulate common and important activities of daily living (ADL). The tasks (summarized in table 3) match those used in previous studies (Magermans, 2004, Murrery & Johnson, 2004), allowing comparison of results to young mobile populations. Each task was performed three times, resulting in 18 total trials. All trials, including repeats, were performed in a randomized order. Participants were given a starting and end position and the description of the task as detailed below. In order to mimic the performance of activities of daily living, no other guidance was given so that the participant would perform the tasks as naturally as possible. Participants were allowed to rest between trials at their discretion. Total testing time took approximately 1 hour including setup. All trials, with the exception of the perineal care trials, were performed with the participant seated on a 43 cm high chair. The perineal care trials were performed with the participant seated on a 43 cm high stool to preclude interference in motion from the back of the chair.

Table 3: Activity of daily living tasks

	Activity	Type of Activity
1	Eat with a spoon	Feeding
2	Combing Hair	Hygiene
3	Washing axilla	Hygiene
4	Perineal care	Hygiene
5	Reach above shoulder	Daily Task
6	Reach above shoulder (scaled to torso height)	Daily Task

i) Eat with a spoon task

The participant was asked to pick up a spoon from table height (66cm) bring the spoon to their mouth and then return the spoon to the table

ii) Hair combing task

The participant was asked to start with their right hand holding a comb and resting on the table then bring their hand to the right side of the crown of the head, the backside of the crown of the head and the left side of the head before returning their hand to the table.

One stroke of the comb was completed at each of the 3 locations on the head.

iii) Washing the axilla task

The participant was asked to start with the right hand resting on the table and then asked to bring their right hand to the left axilla before returning the hand to the table.

iv) Reaching above the shoulder task

This task began with the participant's right hand resting on the table. They were then asked to reach and point to a target located 1.5 m off the ground and centered in front of their body. This task would simulate putting something away on a shelf. This is shown in figure 10 where the yellow mark indicates the target for this reach.

v) Reaching above the shoulder-scaled to torso height

Prior to the beginning of the collection, the researcher measured the distance from the participant's greater trochanter of the hip to the tip of the fingers (with their hand raised high). This task began with the subject's right hand resting on the table. They were then asked to bring their right hand to a target located at 80% of the measured distance plus

the height of the chair (43 cm). The red mark in figure 10 represents the target for this task.



Figure 10: Set up for the reaching tasks

vi) Perineal Care

The participant was seated on a stool (height of 43 cm) with the right hand resting on the table, the participant was asked to bring their hand to their sacrum, a motion comparable to perineal care, before returning their hand to the table.

6.0 Data Analysis

All motion capture data was reviewed and missing data was filled using the pattern fill function in the Vicon 1.2 motion capture system software. This data was used as input into a custom-modified version of the SLAM mathematical model (Dickerson *et al.*, 2007) in Matlab 2008a (Mathworks, Natick, MA) to determine time-varying Euler angles of the humerus with respect to the torso, resultant dynamic right shoulder moment and the objective function determined by the model, which minimizes the sum of the cubed muscle stresses. Euler angles were calculated based on the convention described by Magermans (2004). Rotation order was chosen to be rotations about the y-z-y axis in order to compare to previous research (figure 11). The first rotation is about the torso vertical axis and is defined as the plane of elevation. A second rotation about the local horizontal axis of the humerus is defined as the angle of elevation. Finally, the third rotation, about the long axis of the humerus, is defined as humeral rotation. Maximum values were calculated by taking the mean of the maximal angles found in each of the 3 repetitions performed by each participant.

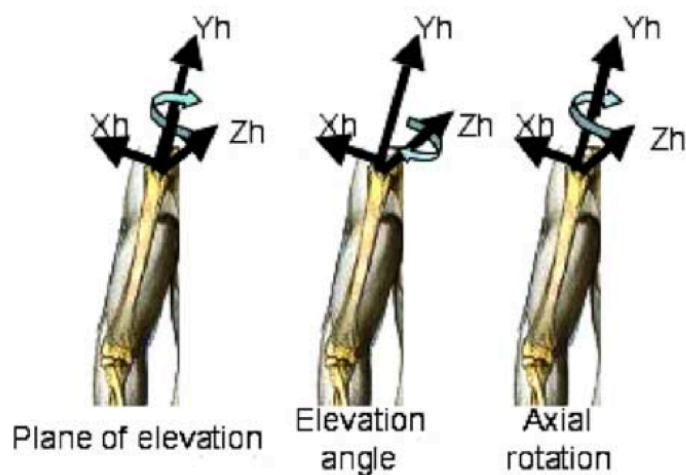


Figure 11: Illustration of the y-z-y Euler rotation sequence (Magermans, 2005)

Since the main objective of this work was to examine humeral kinematics during ADLs in the elderly, the mean velocity of the elbow was examined. The position data of the joint centre of the elbow was filtered using a 2nd order butterworth low pass filter set at 6 Hz. From this data the velocity of the elbow was calculated using the central difference numerical method ($\frac{\partial x_n}{\partial t}$, Equation 1). From the 3 repetitions performed by each participant for each task a mean was calculated.

$$\frac{\partial x_n}{\partial t} = \frac{|x_{n+1} - x_{n-1}|}{2\Delta t} \quad (1)$$

where x is a data point n is the nth (current) frame
 Δt is the time between consecutive frames

The position data was used as input into the SLAM mathematical model (Dickerson *et al.*, 2007) to determine the objective function magnitude for each trial. A mean of the objective function for each participant in each task was calculated from the 3 repetitions. The objective function is the minimum sum of the cubed muscle stresses during the task and provides us with an understanding of the overall muscular effort required by the task. All mean data is presented as a least square mean to account for the different number of participants in the mobile and impingement populations. Table 4 provides of a summary of the output data and the method used to obtain it.

Table 4: Summary time series output data

	Output	Output Source	Type of Data
1	Resultant external shoulder moment	SLAM	mean
2	Objective function magnitude	SLAM	mean
3	Resultant elbow velocity	Motion Data	mean
4	Plane of elevation	SLAM	Time series and range
5	Angle of elevation	SLAM	Time series and range
6	Humeral rotation	SLAM	Time series and range

6.1 Summary Statistics

Summary statistics were calculated for all trials collected (ROM and ADL). Section 6.1.1 and 6.1.2 will describe what summary statistics were calculated for the ROM and ADL trails respectively.

6.1.1 Summary Statistics for ROMs

Maximal and minimal angles were calculated for each ROM task. The range of motion for each pertinent angle in each ROM task was calculated by subtracting the average minimum angle from the average maximum angle for each participant for each task. A two-tailed t-test with a factor of injury status was performed on the angle of interest for each ROM task in order to determine if the means of the two groups showed statistically significant differences. An alpha level of less than 0.05 was considered significant for all trials with the exception of the angles. Table 5 summarizes what angles were expressed for each range of motion.

Table 5: Summary of Angles of interest for each ROM task

Range of Motion	Angles of interest
Flexion	Maximum angle of elevation
Extension	Minimum angle of elevation
Abduction	Maximum angle of elevation
Internal rotation	Maximum humeral rotation
External rotation	Minimum humeral rotation
Flexion/extension	Total range of angle of elevation
Internal external rotation	Total range of humeral rotation

6.1.2 Summary Statistics for ADLs

The following values were determined for each ADL task collected;

- Mean resultant external shoulder moment for the task
- Mean objective function for the task
- Mean elbow velocity for the task
- Range of plane of elevation
- Range of angle of elevation
- Range of humeral rotation

A 2-way repeated measures ANOVA (injury status and task) was run for each of the 6 outcome measures (range of plane of elevation, range of angle of elevation, range of humeral rotation, resultant velocity, resultant external shoulder moment and objective

function) and tested for main and interaction effects. A Student's t post-hoc analysis was conducted when statistically significant differences were found. Statistical significance was considered at $\alpha = 0.05$.

The k-means clustering analysis algorithm was used to classify subjects based on a number of variables into k clusters. A value of k=2 was chosen to correspond to the two populations studied in this investigation. K-means clustering is accomplished by minimizing the some of the square Euclidian distance between the data and the corresponding centroid or cluster centre. For this investigation it was used to determine if the two groups could be identified by a combination of the mean elbow velocity, mean resultant external shoulder moment, mean objective function and the ranges of each of the three Euler angles. These variables were chosen as they corresponded to highest success rate of the k-means clustering analysis. This was completed for each ADL task.

6.2 Time Series Data

All time series data was normalized as a percentage of cycle time. Cycle time was defined as starting the moment the subject moved their hand off the start target to the moment that the hand returned to the start target after completing the task. A mean curve was determined for each task and each subject by averaging the outcome measures across the three trials of each task performed by each subject. From this data, a mean curve for all subjects in each group was determined and used for graphical representation of the movement patterns for each group. This process was completed for each of the Euler angles; plane of elevation, angle of elevation and humeral rotation.

7.0 Results

The findings of the study will be presented in two sections: ROM tasks and ADL tasks.

7.1 Results of Range of Motion Tasks

The impingement participant group showed decreased peak angles in all range of motion tasks with the exception of extension and internal rotation (figure 12). Participants in the impingement group had a significantly smaller maximum angle of elevation during the abduction task (p-value of 0.0016). The healthy population had an average peak angle of elevation of $140 \pm 20^\circ$ during the abduction task while the impingement populations reached an average maximum angle of elevation of $96 \pm 30^\circ$ during this task. The maximum angle of elevation during the flexion task was also significantly lower for the impinged population when compared to the healthy participants (p-value of 0.0046). For this task the healthy and impinged populations had mean maximum angles of elevation of $145 \pm 24^\circ$ and $108 \pm 28^\circ$ respectively. Participants suffering with impingements did not show significantly decreased range of motion in extension with the healthy population having an average minimum angle of elevation of $-23 \pm 24^\circ$ and the impingement population having an average of $-4 \pm 26^\circ$. No decreased range of motion was found for the impingement population in internal rotation (p-value of 0.11). Healthy and impingement populations had mean maximum humeral rotations of $5 \pm 24^\circ$ and $-8 \pm 12^\circ$ respectively. The large standard deviations found in both populations extension and internal rotation may account for the lack of significant differences between the two populations. Significant differences were found in external rotation, with the impinged populations showing a decreased range of motion when compared to the healthy controls.

The impinged population had an average maximal rotation of $-76 \pm 27^\circ$ while the healthy population had an average of $-107 \pm 22^\circ$.

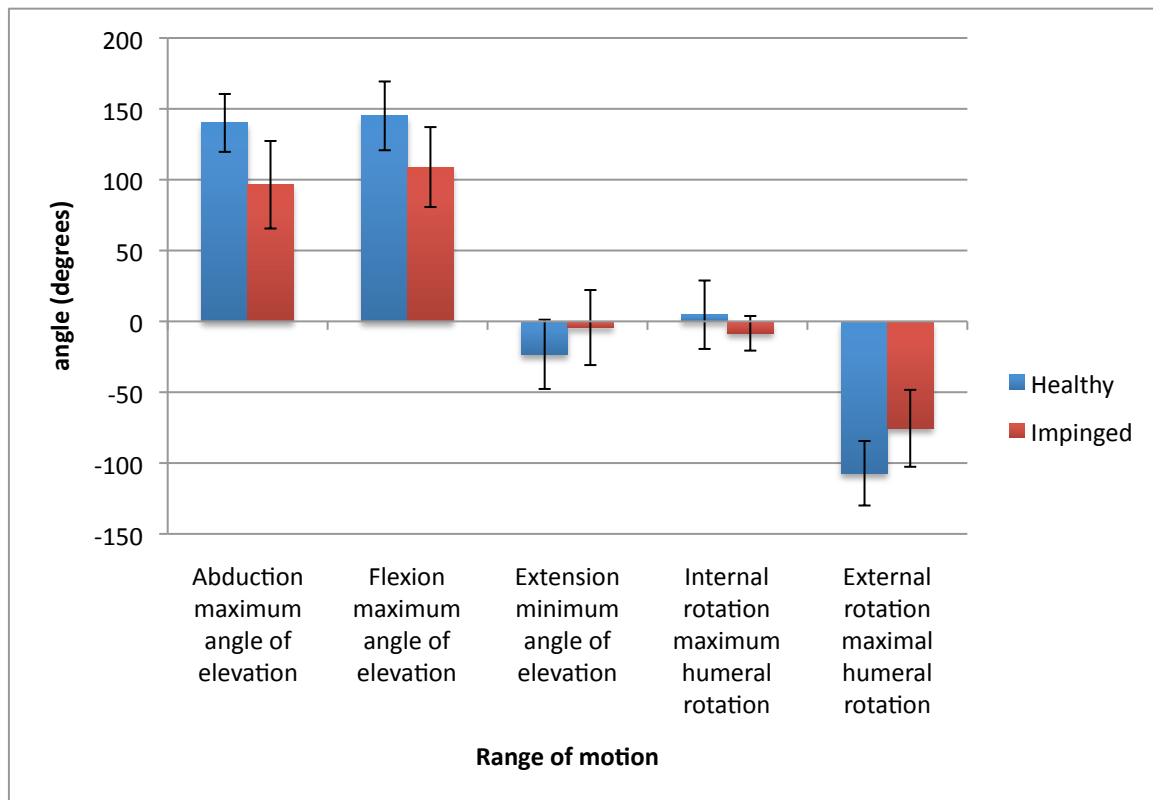


Figure 12: Results of maximum Euler angles during ROM tasks

Ranges of flexion/extension and internal/external rotation were significantly different between the two populations. Healthy patients showed a flexion extension range of $168 \pm 44^\circ$. The impinged populations showed a significantly smaller (p-value of 0.0059) flexion/extension range of $113 \pm 42^\circ$. External/Internal rotation showed similar decreases in range (p-value of 0.0039) for the impinged population with a range spanning $67 \pm 24^\circ$ versus $112 \pm 41^\circ$ for the mobile population. Table 5 summarizes the results of these tests

Table 5: Range results for range of motion tasks

Range	Injury Status	Least square mean (°)	Standard deviation (°)	p-value
Flexion/Extension Range	Healthy	168	44	0.0059
	Impinged	113	42	
External/Internal rotation range	Healthy	112	41	0.0039
	Impinged	67	24	

7.2 Results of Activities of Daily Living Tasks

The results of the evaluation of the ADL tasks have been provided as a sub-section for each of the analyses used: the ANOVA analysis, the time series data and the clustering analysis.

7.2.1 Results of the ANOVA Analysis

The findings of the ANOVA analysis are described according to each of the 6 variables of interest.

Range of plane of elevation

Significant differences in maximum plane of elevation occurred between tasks ($p < .0001$). The perineal care task required a significantly higher range of plane of elevation ($103 \pm 28^\circ$) than all other tasks (Figure 13). The hair-combing task had a higher range than all tasks (excluding parineal care) with a mean range of plane of elevation of $36 \pm 21^\circ$. The reach, scaled reach, eating with a spoon and washing the axilla task all showed similar ranges of plane of elevations with values of $15 \pm 10^\circ$, $14 \pm 9^\circ$, $11 \pm 7^\circ$ and $14 \pm 14^\circ$ respectively. No significant differences (p -

value = 0.1930) were found between the impingement and mobile populations, which had mean range of plane of elevation values of 30 +/- 35° and 35 +/- 38° respectively.

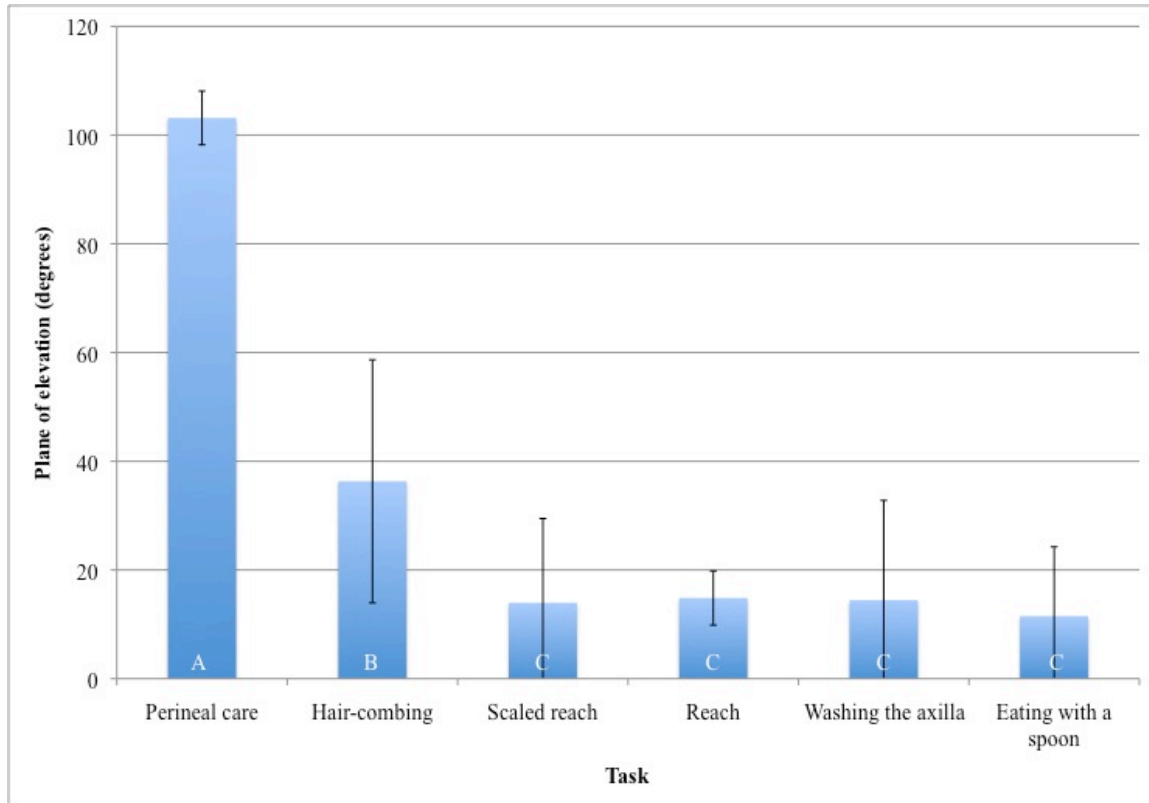


Figure 13: Mean range of plane of elevation angles across task. Levels not separated by the same letter are significantly different.

Range of angle of elevation

Differences in angle of elevation emerged across injury status (p-value=0.0002), task (p-value=<0.0001) and injury status by task interaction effect (p-value=0.0002). Range of angle of elevation for task resulted in 3 levels of significance (Table 6). The reach, scaled reach and hair-combing tasks required larger ranges of angle of elevation than all other tasks. Perineal care required a larger range than eating with a spoon and washing the axilla, which were

statistically similar to each other. The range of angle of elevation was found to be approximately 44% larger for the mobile population (52 +/- 30°) than the impinged population (36 +/-21°)

Table 6: Mean ranges of angle of elevation across tasks. Levels not separated by the same letter are significantly different

Task	Level	Least square mean (°)	Standard deviation (°)
Reach	A	65	65
Scaled reach	A	61	61
Hair-combing	A	57	57
Perineal care	B	44	44
Eating with a spoon	C	20	20
Washing the axilla	C	16	16

Analysis of the interaction between task and injury showed that range of angle of elevation was not significantly different between injury groups for all tasks (Figure 14). Significantly different ranges were found for the reach, scaled reach and hair-combing tasks. All other tasks were considered to have ranges that were statistically similar between injury groups. Mean ranges of angle of elevations and standard deviations across all tasks and injury levels are summarized in Table 7.

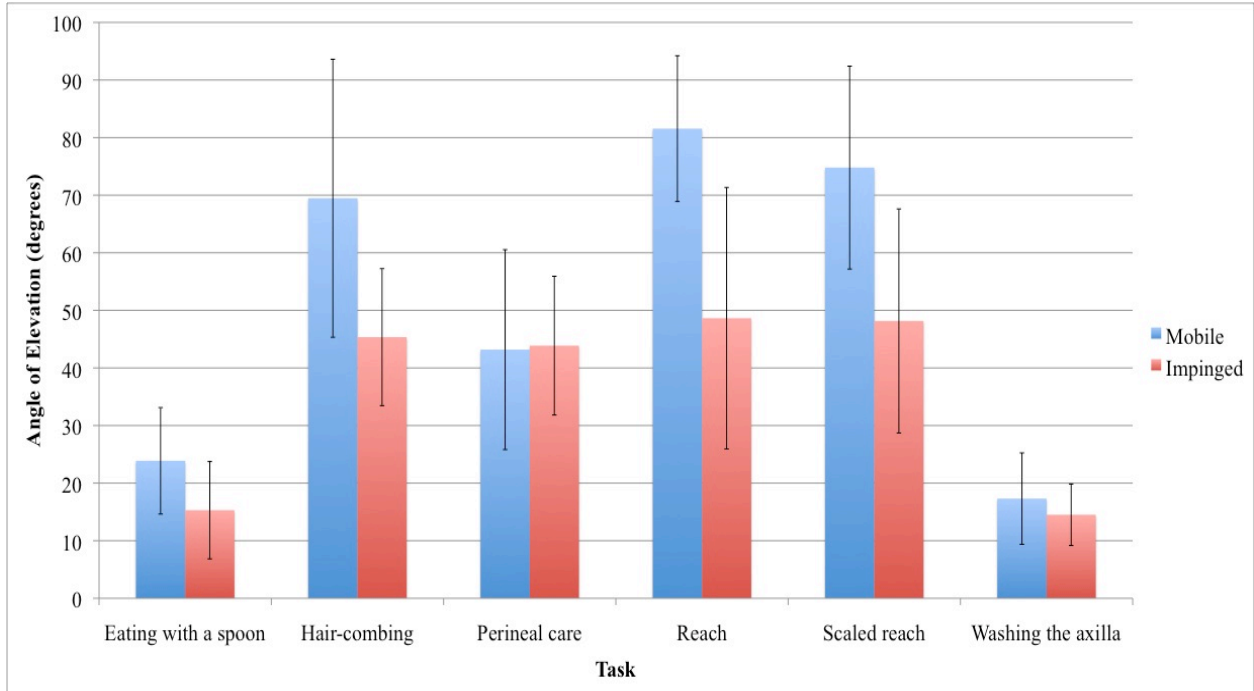


Figure 14: Mean range of angle of elevation interaction between injury status and task. Levels not separated by the same letter are significantly different.

Table 7: Mean range of angle elevation interaction between injury status and task. Levels not separated by the same letter are significantly different.

Task	Injury status	Level	Least square mean (°)	Standard deviation (°)
Eating with a spoon	Mobile	D	24	9
	Impinged	D	15	8
Hair-combing	Mobile	B	69	24
	Impinged	C	45	12
Perineal care	Mobile	C	43	17
	Impinged	C	44	12
Reach	Mobile	A	82	13
	Impinged	C	49	23
Scaled reach	Mobile	A, B	75	18
	Impinged	C	48	19
Washing the axilla	Mobile	D	17	8
	Impinged	D	15	5

Range of humeral rotation

Both injury status and task elicited significant differences in mean range of humeral rotation with p-values of 0.0083 and <0.0001 respectively. The perineal care task required the largest range of humeral rotation (117 +/- 28°), followed by hair-combing (56 +/- 19°), washing the axilla (39 +/- 13°) and eating with a spoon (21 +/- 9°), reach (20 +/- 10°) and scaled reach (20 +/- 9°) (Figure 15). Participants with impingements had significantly lower ranges of humeral rotations during the tasks than the healthy population with ranges of 40 +/- 40° and 51 +/- 36° respectively.

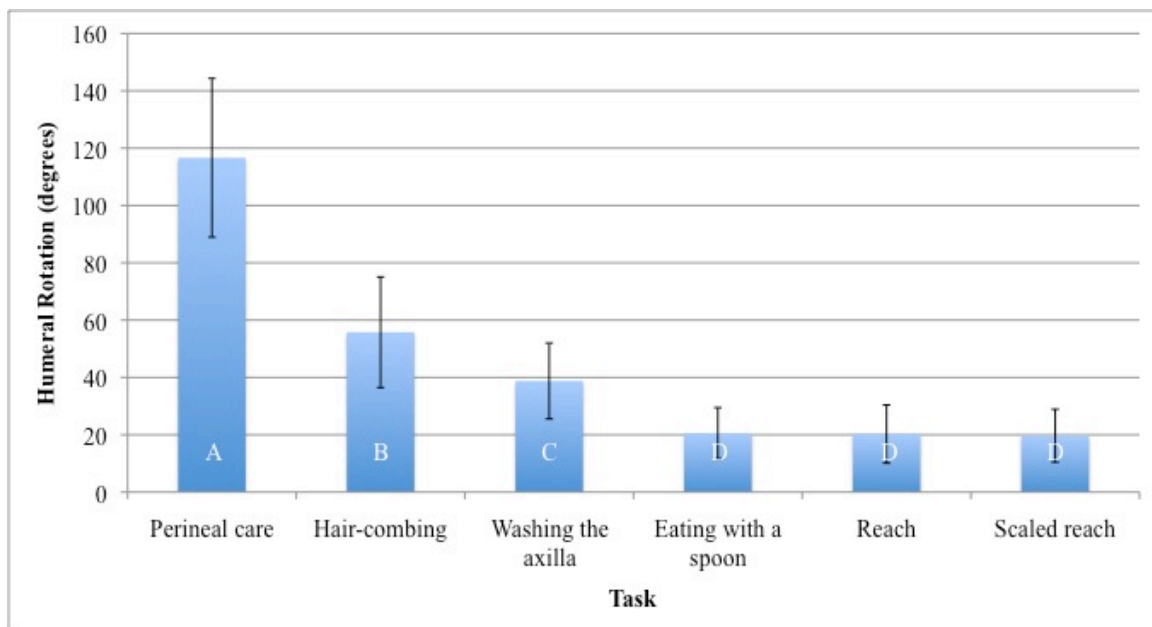


Figure 15: Mean range of humeral rotation across tasks. Levels not identified by the same letter are significantly different

Velocity

Few differences were seen in mean velocity. Significant differences were only found across tasks (p-value=<0.0001). Perineal care had a significantly higher velocity than all other tasks (Figure 16). The two reaching tasks (reach and scaled reach)

were statistically similar and higher than hair combing and eating with a spoon.

Washing the axilla was similar to the reach and also higher than hair combing and eating with a spoon. All least square means for velocity by task are summarize in table 8.

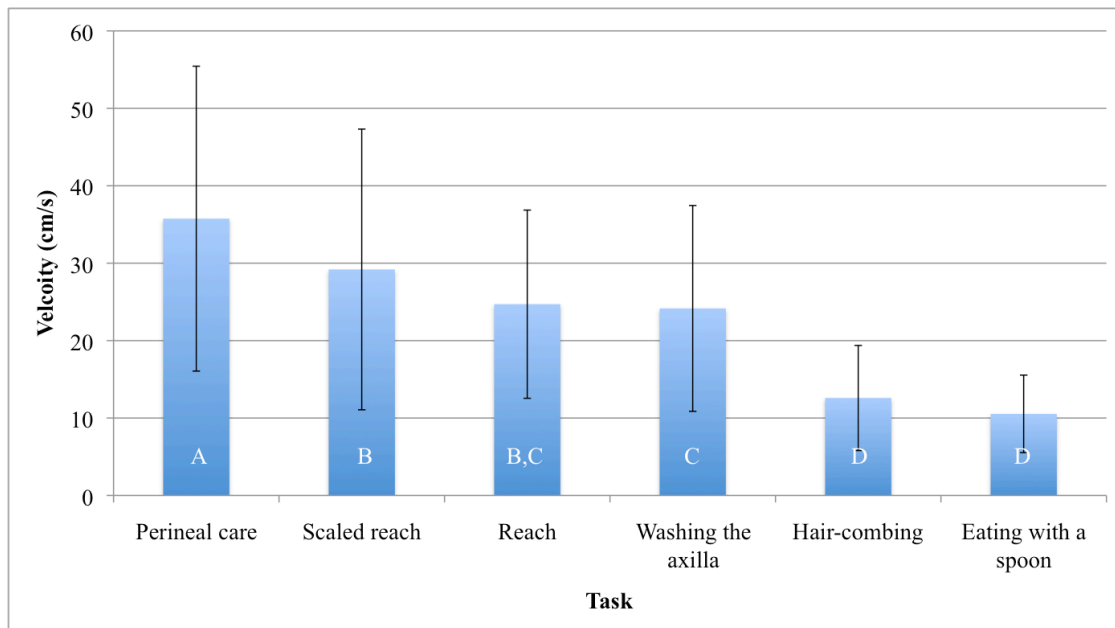


Figure 16: Mean velocity across tasks. Levels not separated by the same letter are significantly different

Table 8: Mean velocity across tasks. Levels not separated by the same letter are significantly different

Task	Level	Least square mean (cm/s)	Standard deviation (cm/s)
Perineal care	A	35.75	19.69
Scaled reach	B	29.19	18.13
Reach	B, C	24.70	12.15
Washing the axilla	C	24.15	13.29
Hair-combing	D	12.59	6.79
Eating with a spoon	D	10.53	5.01

Mean resultant external shoulder moment

Task elicited significant differences in mean resultant external shoulder moment (p-value <-0.0001). Scaled reach and reach required a significantly higher mean resultant external shoulder moment than all other tasks. Hair combing had a higher moment than eating with a spoon, washing the axilla and perineal care, which were all statically similar. Table 9 shows the least square means and standard deviations for all tasks.

Table 9: Mean resultant external shoulder moments by task. Levels not separated by the same letter are significantly different.

Task	Level	Least square mean (Nm)	Standard deviation (Nm)
Scaled reach	A	7.19	1.56
Reach	A	7.09	1.61
Hair-combing	B	5.37	1.32
Eating with a spoon	C	4.87	1.46
Washing the axilla	C	4.84	1.51
Perineal care	C	4.69	1.14

A significant task by injury status interaction effect was present for mean resultant external should moment (p-value= 0.0295). Seven levels of significance emerged from the post-hoc analysis (Figure 17). This analysis yielded evidence that no tasks required different mean resultant external shoulder moments between injury groups.

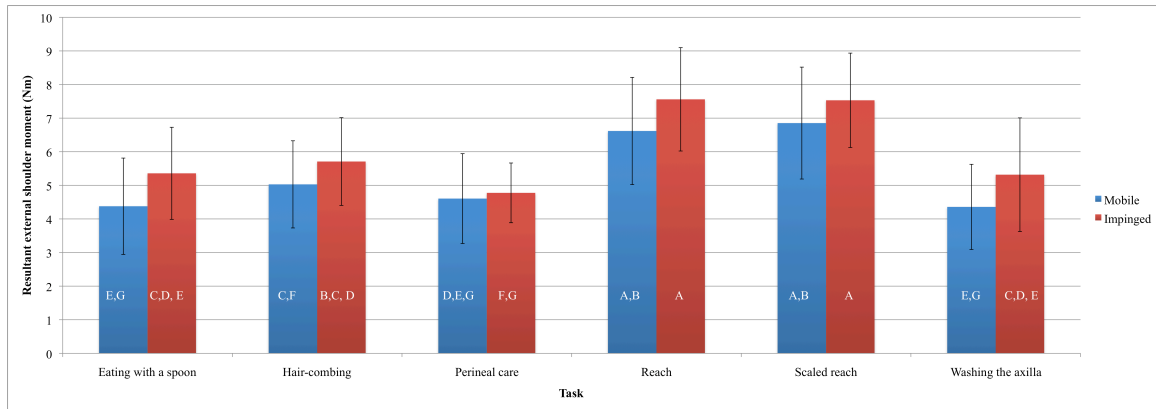


Figure 17: Mean resultant external shoulder moments interaction between task and injury status. Levels not separated by the same letter are significantly different.

Objective function

Task differences existed for mean objective function (p-value=0.013). Three levels emerged from the post-hoc analysis (Table 10). The reach task had the highest objective function followed by the scaled reach, hair-combing, perineal care, washing the axilla and eating with a spoon tasks. The effect of injury status was not found as a main effect. However the standard deviation for the impingement group was found to be much higher than that of the mobile population, 167771 +/- 394756 and 97855 +/- 181970 respectively.

Table 10: Mean objective function by task

Task	Level	Least squares mean	Standard deviation
Reach	A	284842	342480
Scaled reach	A	243427	236440
Hair-combing	A, B	196239	541593
Perineal care	B, C	60047	121098
Washing the axilla	C	8372	13722
Eating with a spoon	C	3951	7083

7.2.2 Results of the Time Series Data.

The results of the time series data is presented in sub-sections according to task

i) Eat with a spoon task

Figure 18, 19 and 20 show the average curves for each population for each Euler angle.

The patterns observed in the plane of elevation graph (figure 18) are similar between the impinged and mobile populations with similar standard deviations. The patterns and standard deviations observed in both angle of elevation and humeral rotations are also similar between the two populations.

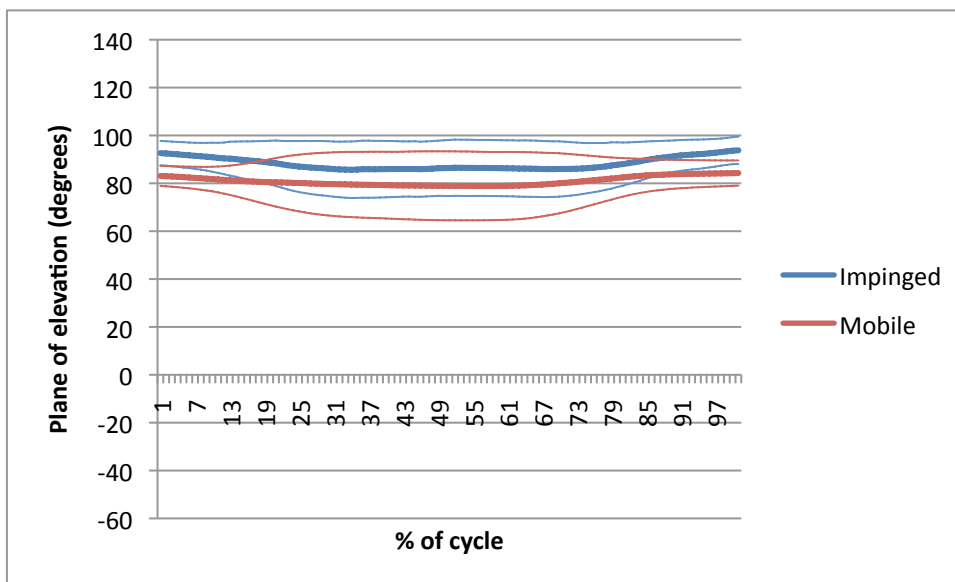


Figure 18: Plane of elevation time series curves for the eating with a spoon task. Dotted lines represent standard deviations.

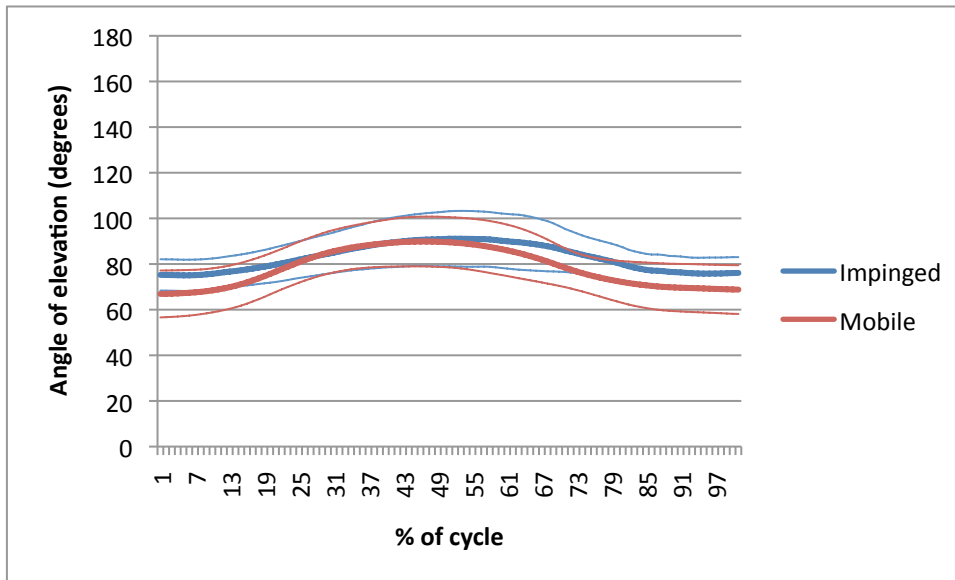


Figure 19: Angle of elevation time series curves for the eating with a spoon task. Dotted lines represent standard deviations.

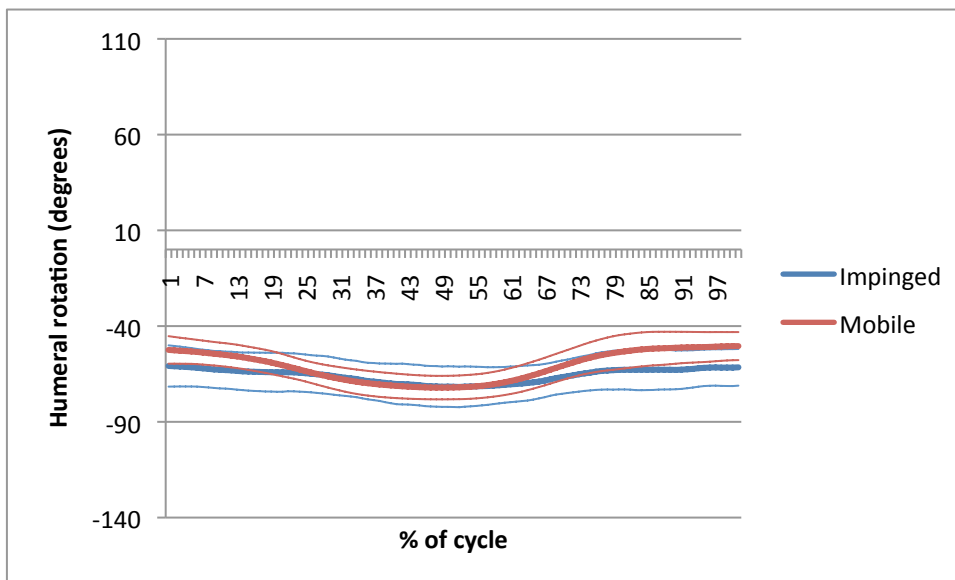


Figure 20: Humeral rotations time series curves for the eating with a spoon task. Dotted lines represent standard deviations.

ii) Hair-combing

Figure 21 shows that similar patterns are seen between the impinged and healthy population in plane of elevation during the hair combing task. However the standard deviation for the healthy population is much greater than that of the impingement population. Some small variations occur in angle of elevation (figure 22) with the

impinged population showing (visually) an extra decrease at approximately 70% of the cycle. Humeral rotation patterns (figure 23) are similar between the two populations.

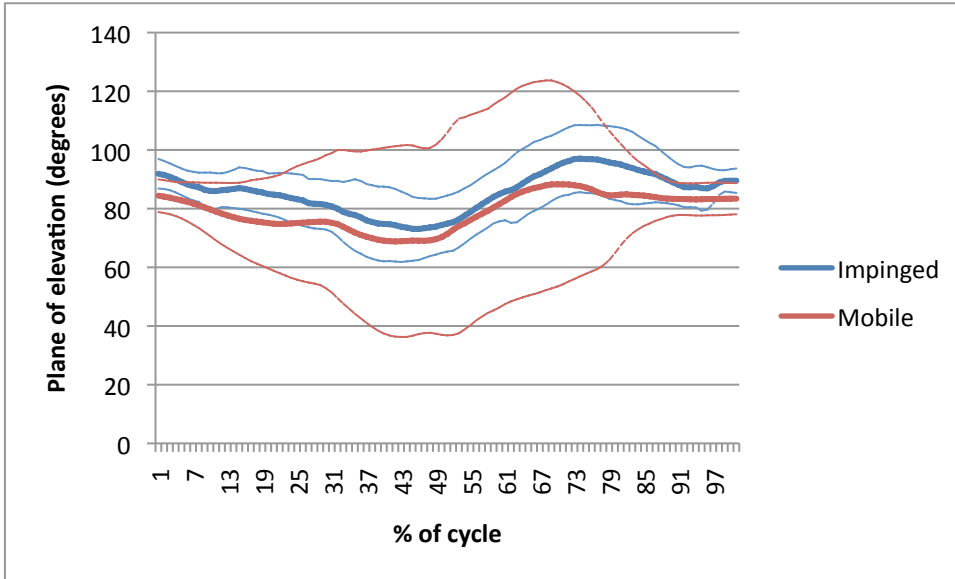


Figure 21: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.

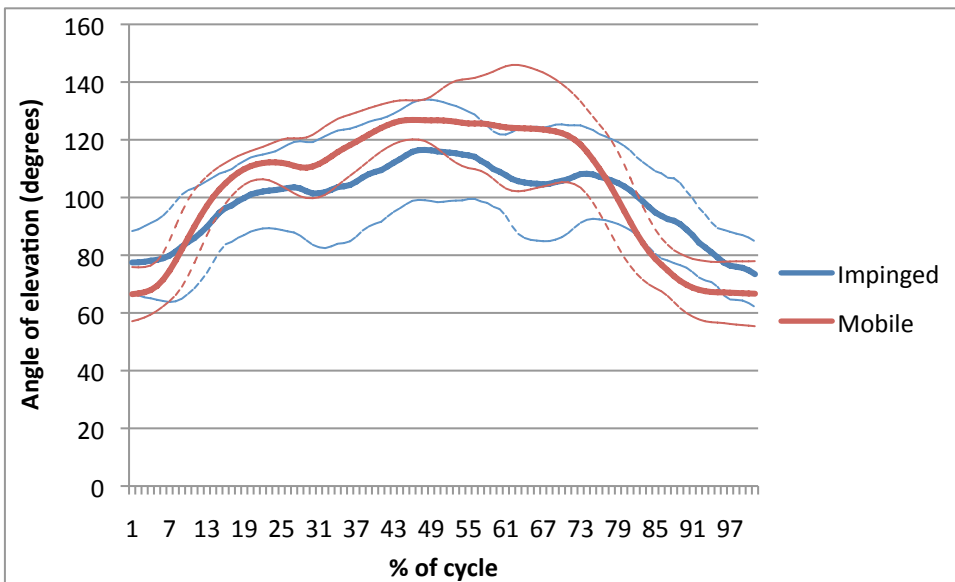


Figure 22: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.

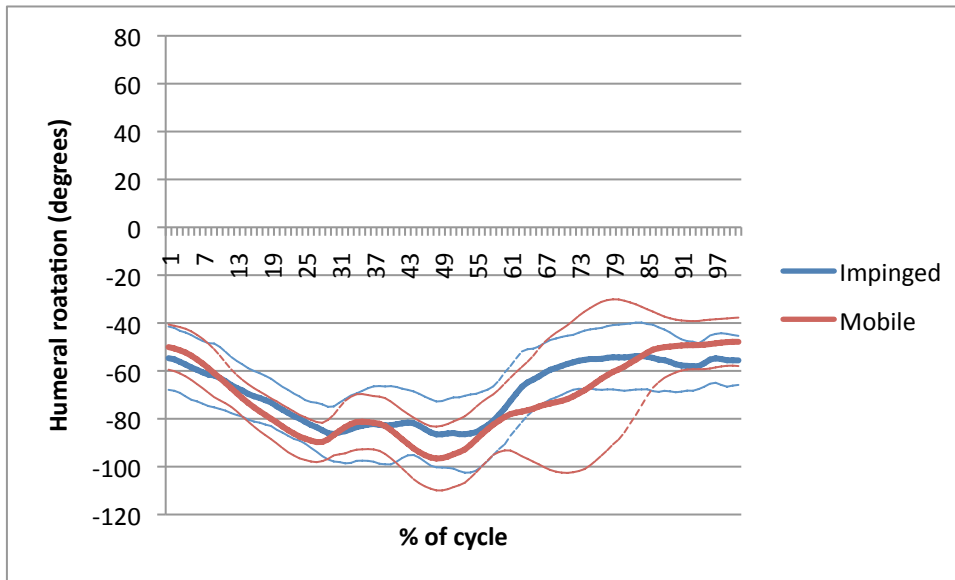


Figure 23: Plane of elevation time series curves for the hair combing task. Dotted lines represent standard deviations.

iii) Washing the axilla

Figure 24, 25 and 26 show the average normalized curves for plane of elevation, angle of elevation and humeral rotation respectively. All 3 curves are quite similar in shape and have similar standard deviations for both the impinged and mobile populations.

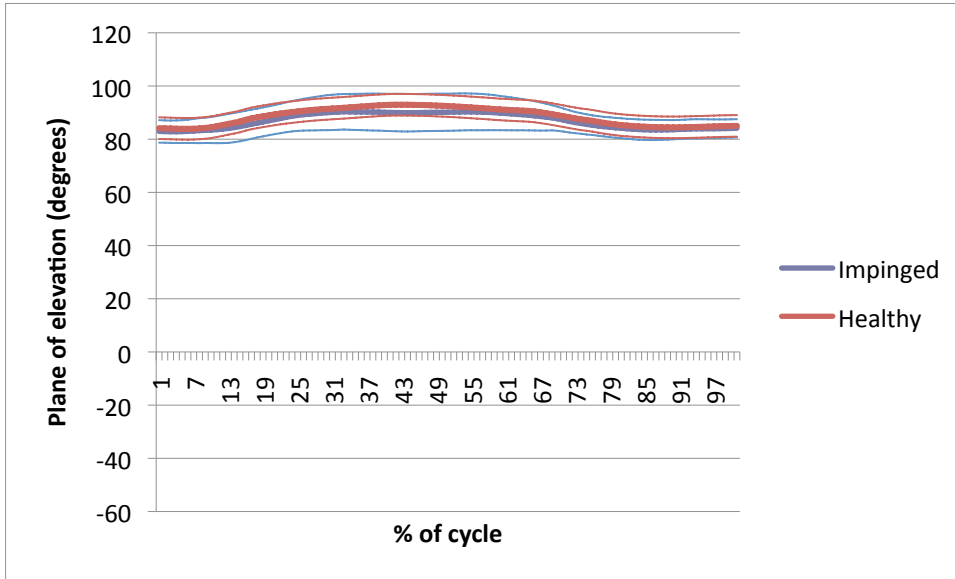


Figure 24: Plane of elevation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.

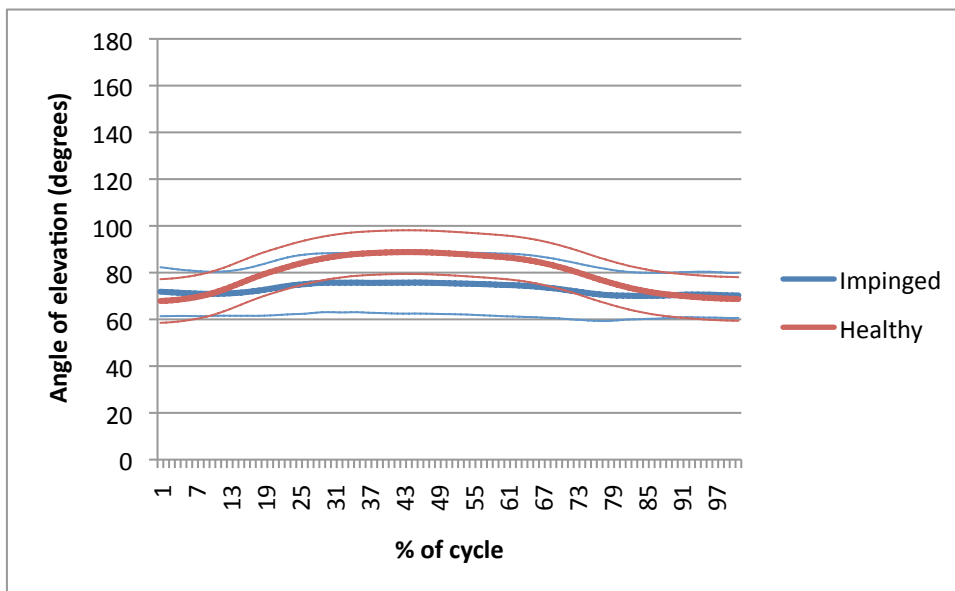


Figure 25: Angle of elevation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.

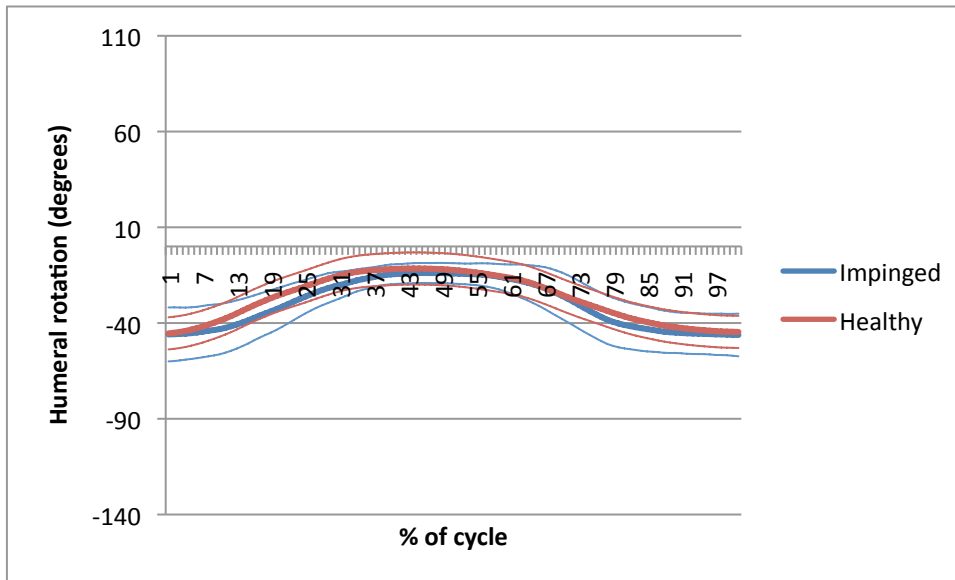


Figure 26: Humeral rotation time series curves for the washing with the axilla task. Dotted lines represent standard deviations.

iv) Perineal care

All 3 average curves (Figure 27, 28 and 29) show similar trends during the perineal care task. The mobile population appeared to have larger standard deviation for plane of elevation while the impinged look to have larger standard deviations for both angle of elevation and humeral rotations. Humeral rotations visually differed at approximately 40% of cycle where it appears that the impinged population did not reach as high internal rotations as the healthy population (seen in figure 29).

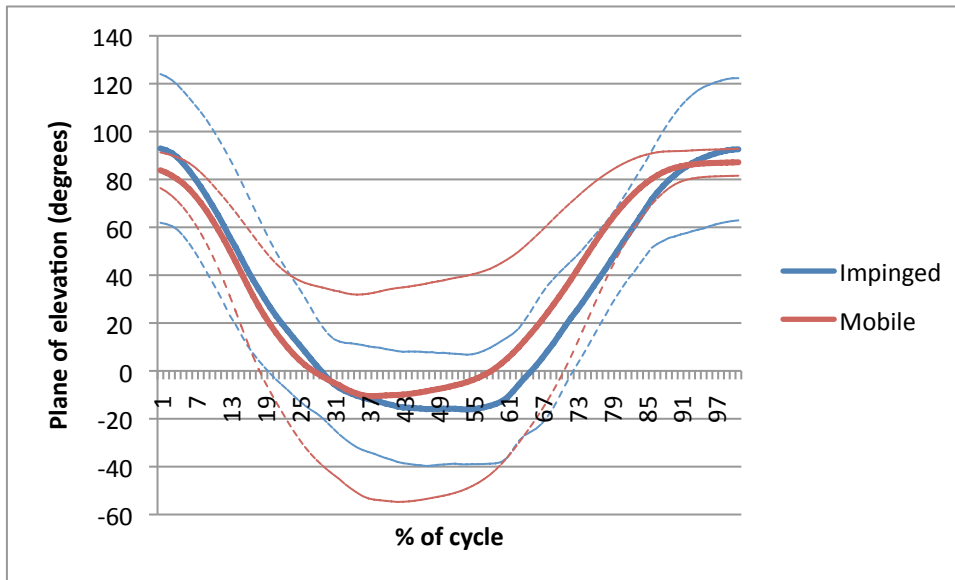


Figure 27: Plane of elevation time series curves for the perineal care task. Dotted lines represent standard deviations.

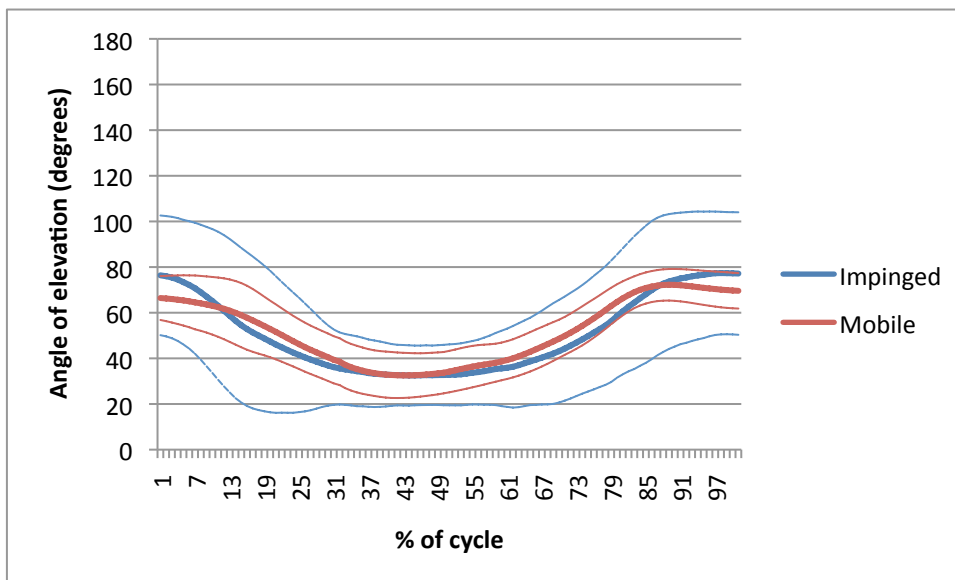


Figure 28: Angle of elevation time series curves for the perineal care task. Dotted lines represent standard deviations.

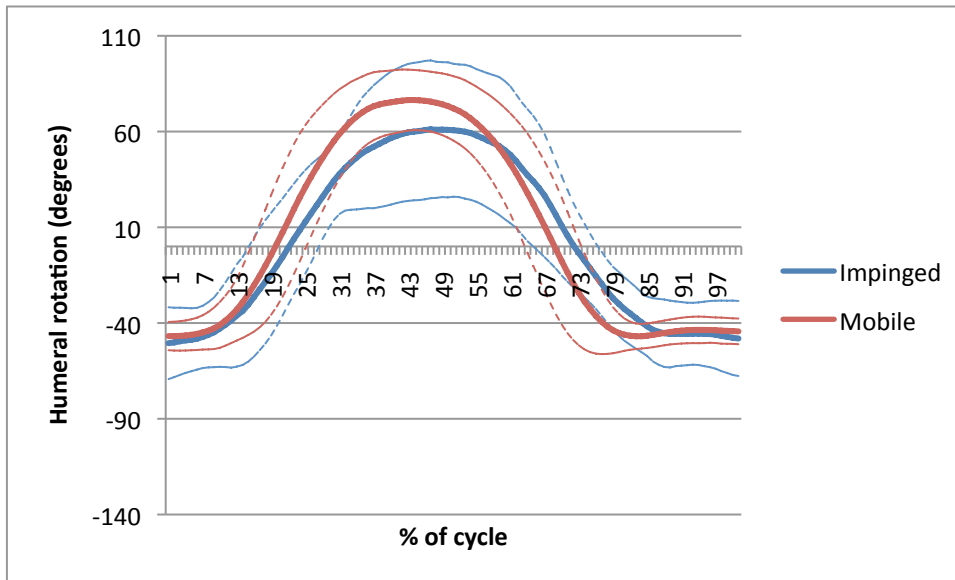


Figure 29: Humeral rotation time series curves for the perineal care task. Dotted lines represent standard deviations.

v) Reaching above the shoulder

The average euler angle curves are quite similar between populations for the reach task. Both the impinged and healthy population have comparable trends for plane of elevation and humeral rotations (figure 30 and 32). Participants suffering with impingements did not reach as high angles of elevation as the mobile population (figure 31).

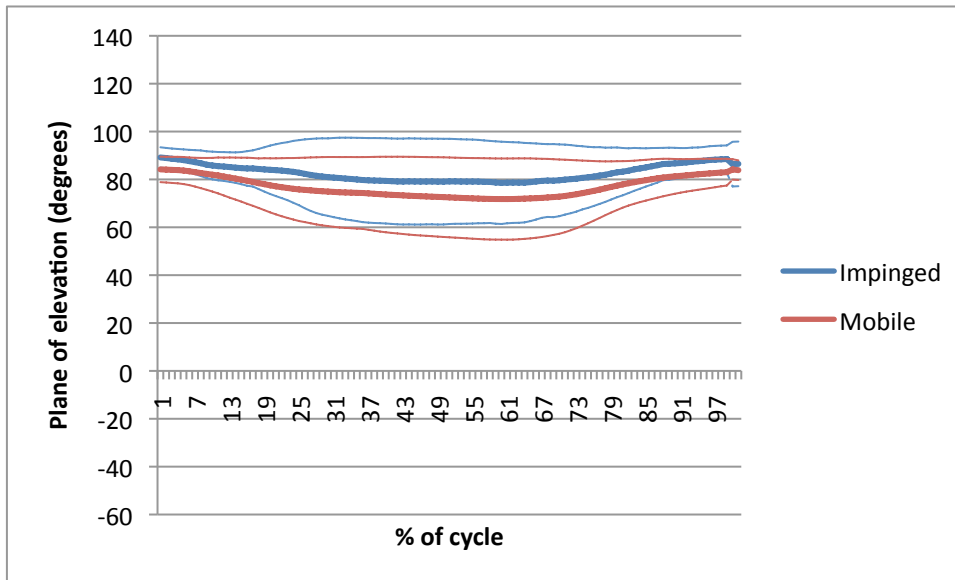


Figure 30: Plane of elevation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.

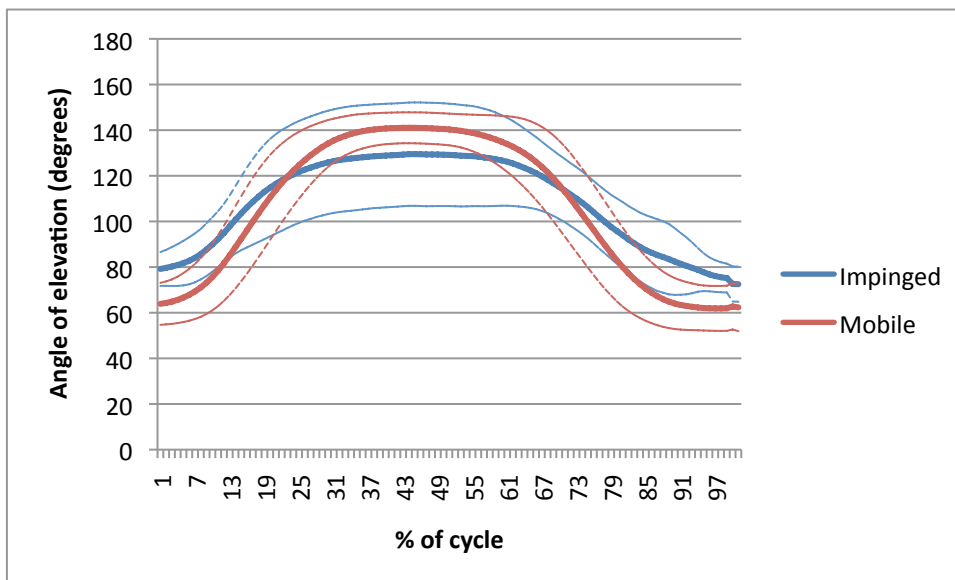


Figure 31: Angle of elevation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.

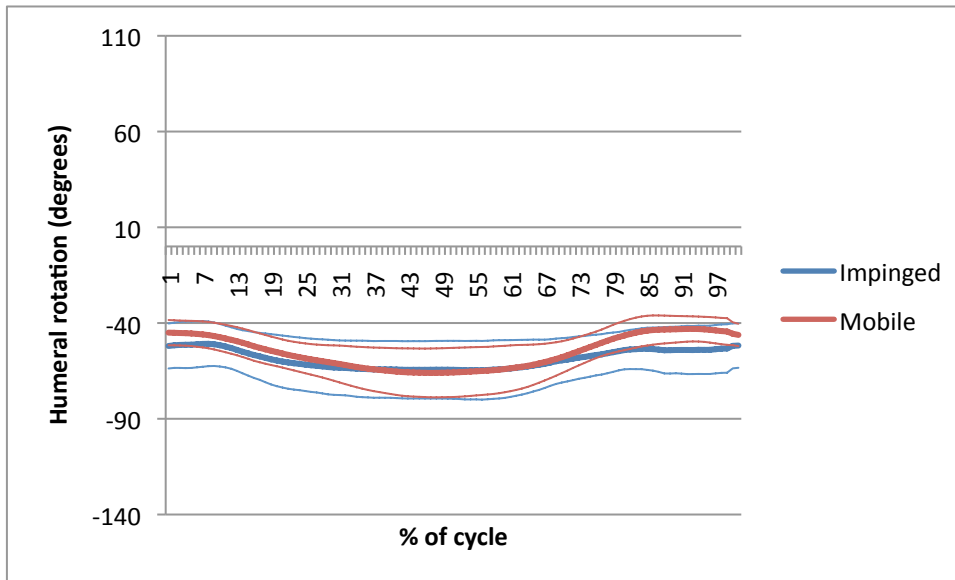


Figure 32: Humeral rotation time series curves for the reaching above the shoulder task. Dotted lines represent standard deviations.

vi) Scaled reaching above the shoulder

Trends are similar in the two populations for plane of elevation (figure 33) and humeral rotation (figure 34) during the scaled reaching task. The general pattern of angle of elevation (figure 35) is comparable between impinged and healthy populations, however the impinged population visually seems to have a smaller peak angle and a higher standard deviation than the mobile population.

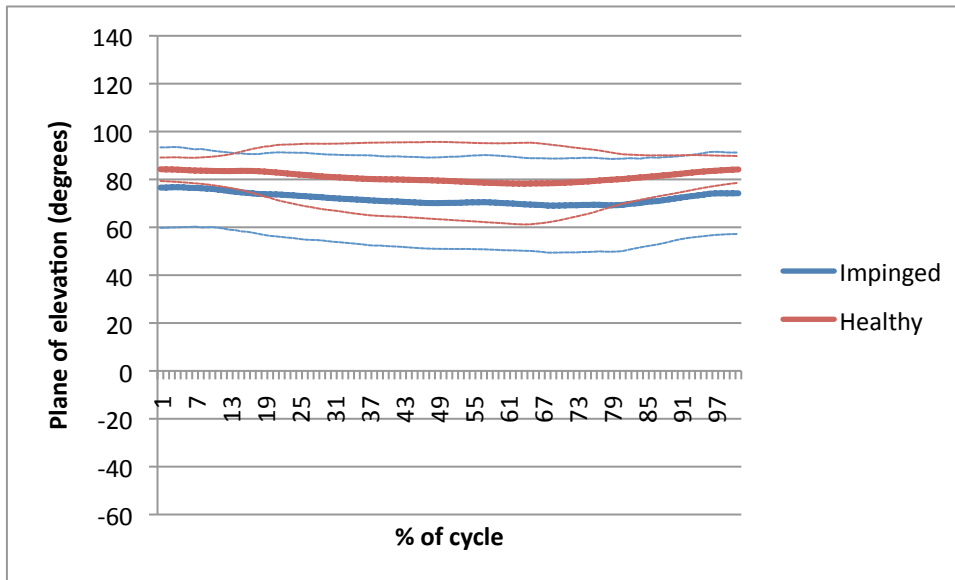


Figure 33: Plane of elevation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.

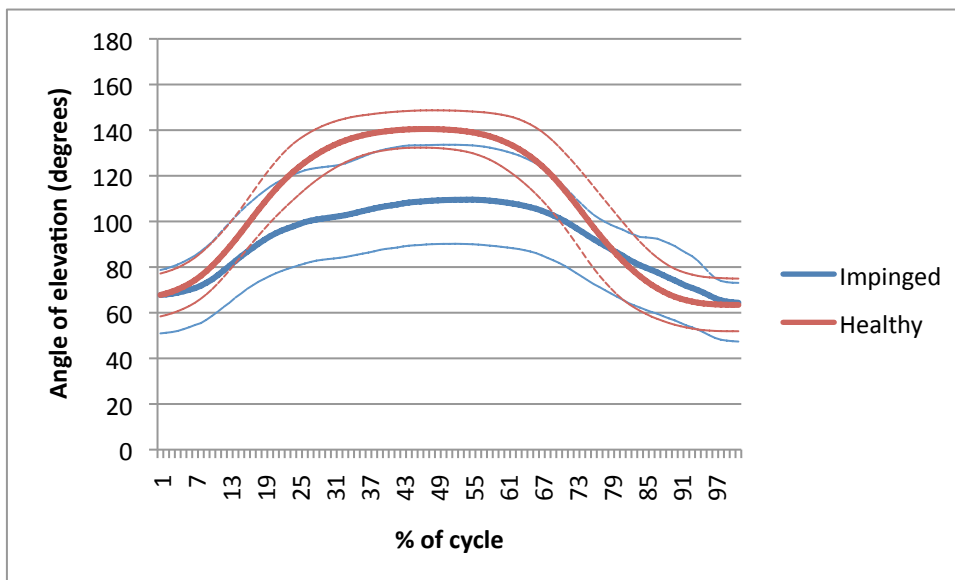


Figure 34: Angle of elevation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.

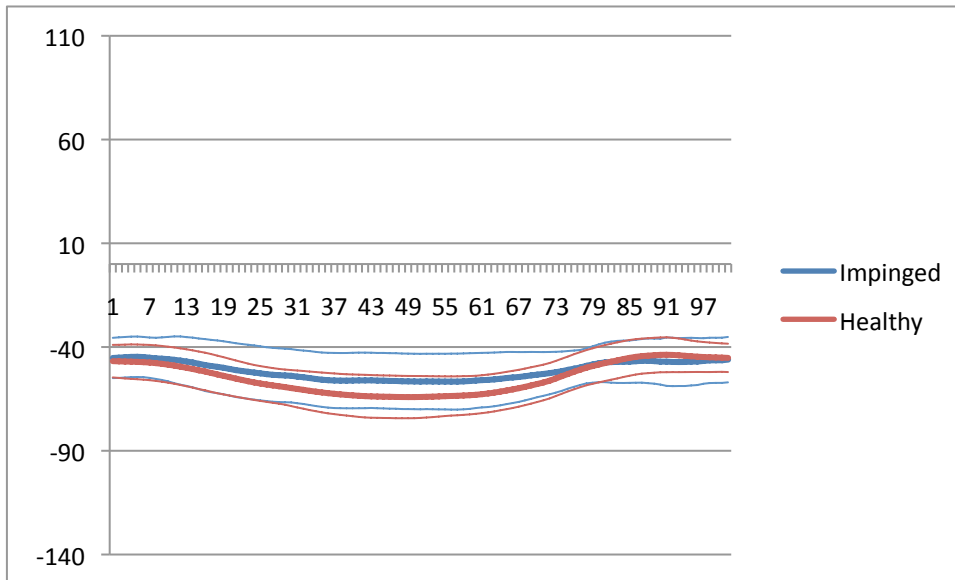


Figure 35: Humeral rotation time series curves for the scaled reaching above the shoulder task. Dotted lines represent standard deviations.

7.2.3 Results of Clustering Analysis

The results of the clustering analysis were relatively unsuccessful. Success rates varied from 77% of the participants classified correctly to all but one participant being classified in the same cluster. This section will examine the results of each cluster analysis by task.

i) Eat with a spoon

The cluster algorithm classified 70% of the participants correctly into two clusters based on the 3 Euler angles ranges, mean velocity and mean moment (Figure 36).

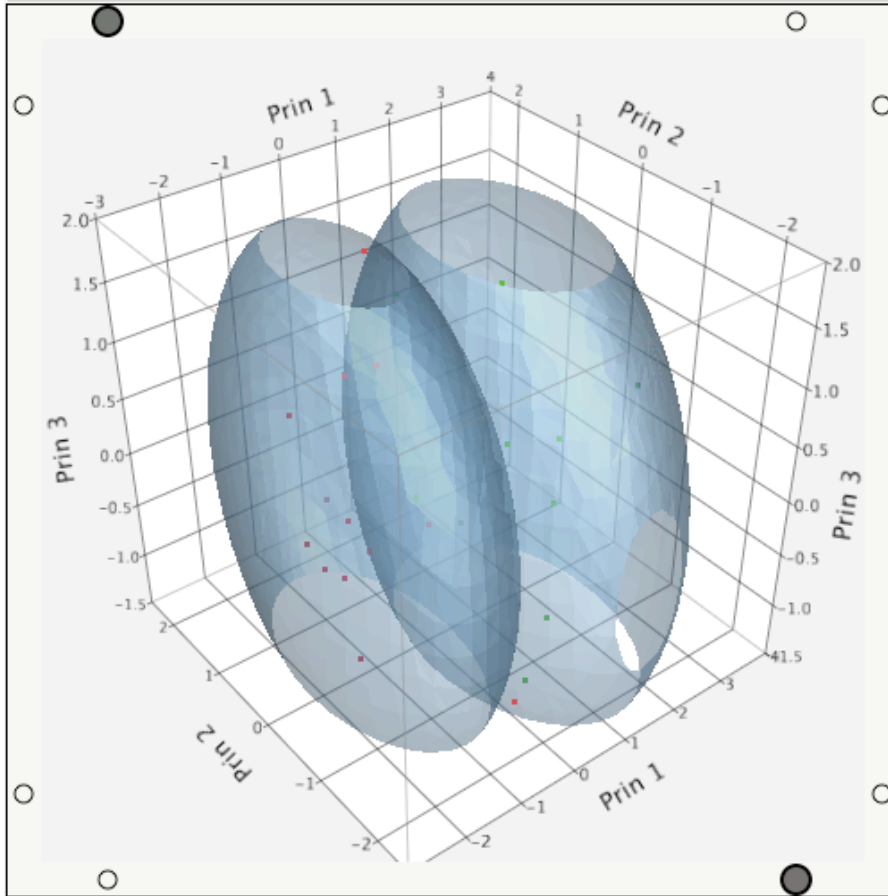


Figure 36: Results of clustering for eating with a spoon task Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingement population lies in the second sphere.

ii) Hair combing task

The cluster algorithm classified 74% of the participants correctly into two clusters based on the 3 Euler angle ranges, mean velocity and mean moment (Figure 37).

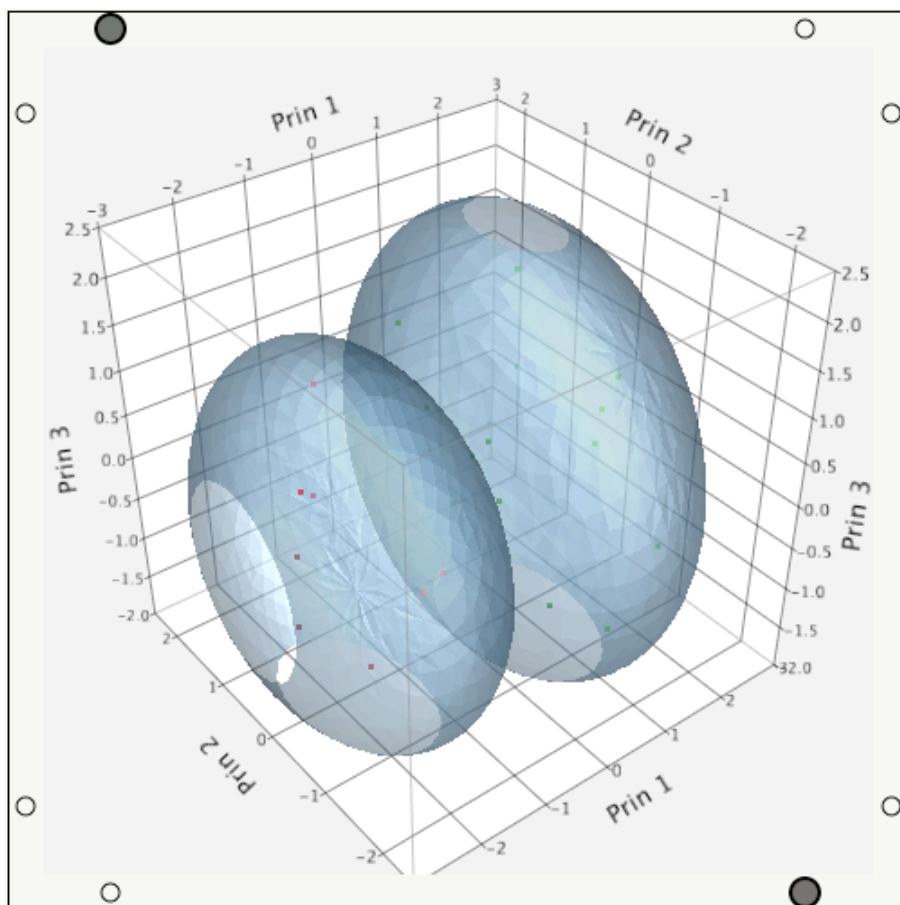


Figure 37: Results of clustering for the hair combing task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingement population lies in the second sphere.

iii) Washing the axilla task

Clustering was not a successful way to identify the healthy and impinged participants in the washing the axilla task as it grouped all participants with the exception of 1 non-impinged participant in the same cluster (Figure 38).

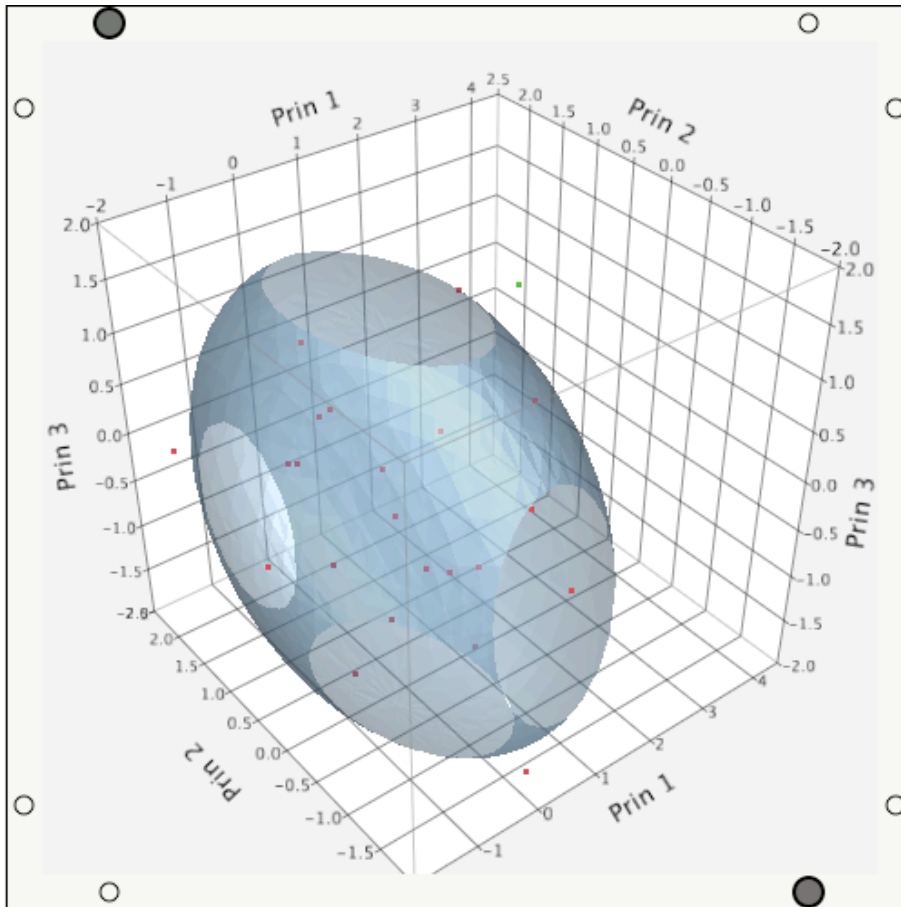


Figure 38: Results of clustering for the washing with the axilla task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.

iv) Perineal care

The clustering techniques were also unsuccessful on the perineal care task as it clustered all participants except 1 in the same cluster (Figure 39).

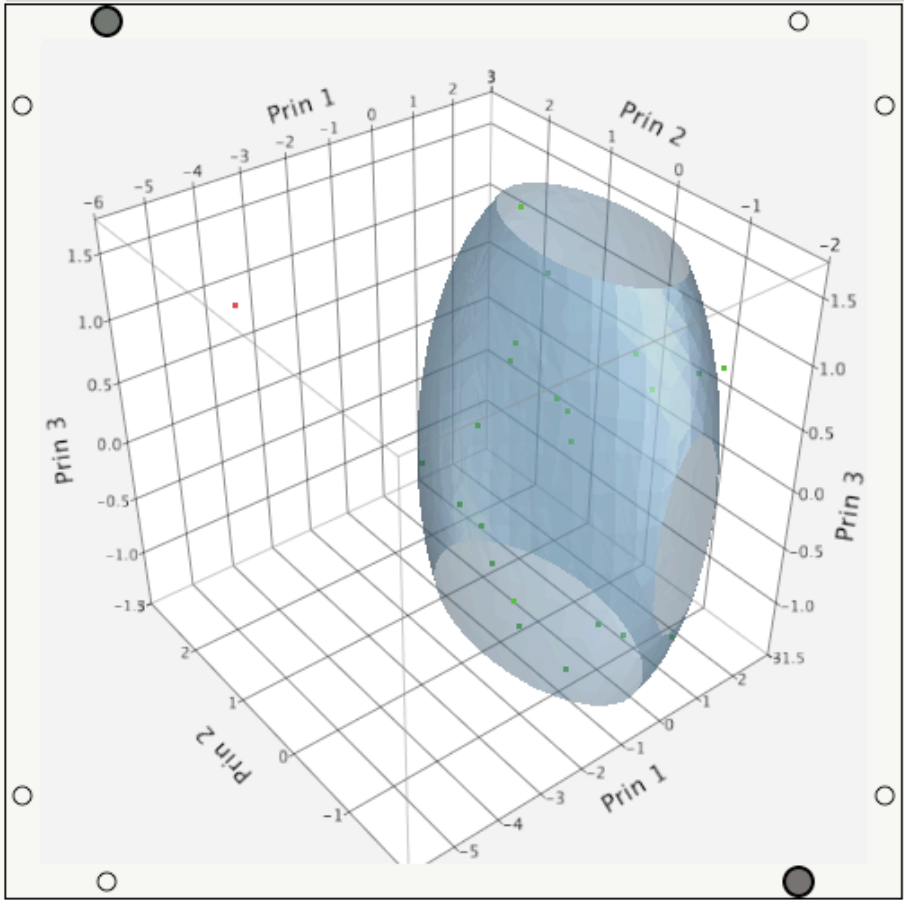


Figure 39: Results of clustering for the perineal care task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.

v) Reaching above the shoulder task

The k-means clustering resulted in 77% of the participants being categorized correctly in the clusters. Figure 40 shows a visual representation of the clusters.

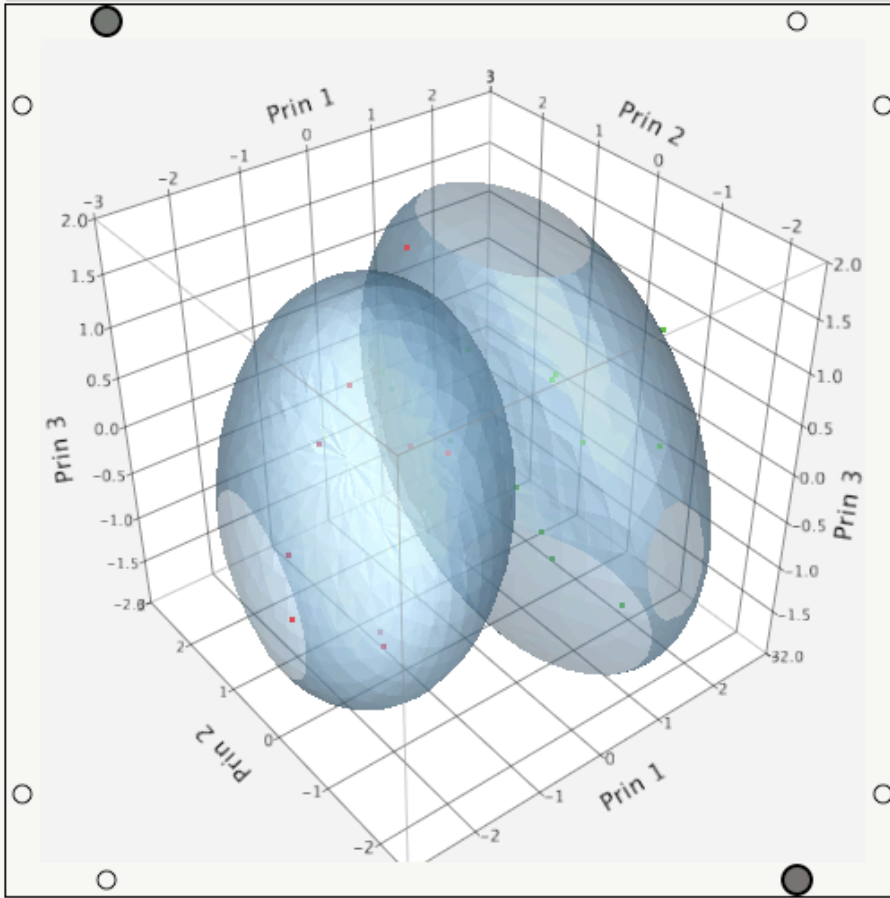


Figure 40: Results of clustering for the reaching above the shoulder task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant. The majority of the impingement population lies in the second sphere.

v) Reaching above the shoulder-scaled to torso height

K-means clustering was not very successful as it grouped all participants together with the exception of 3 (figure 41).

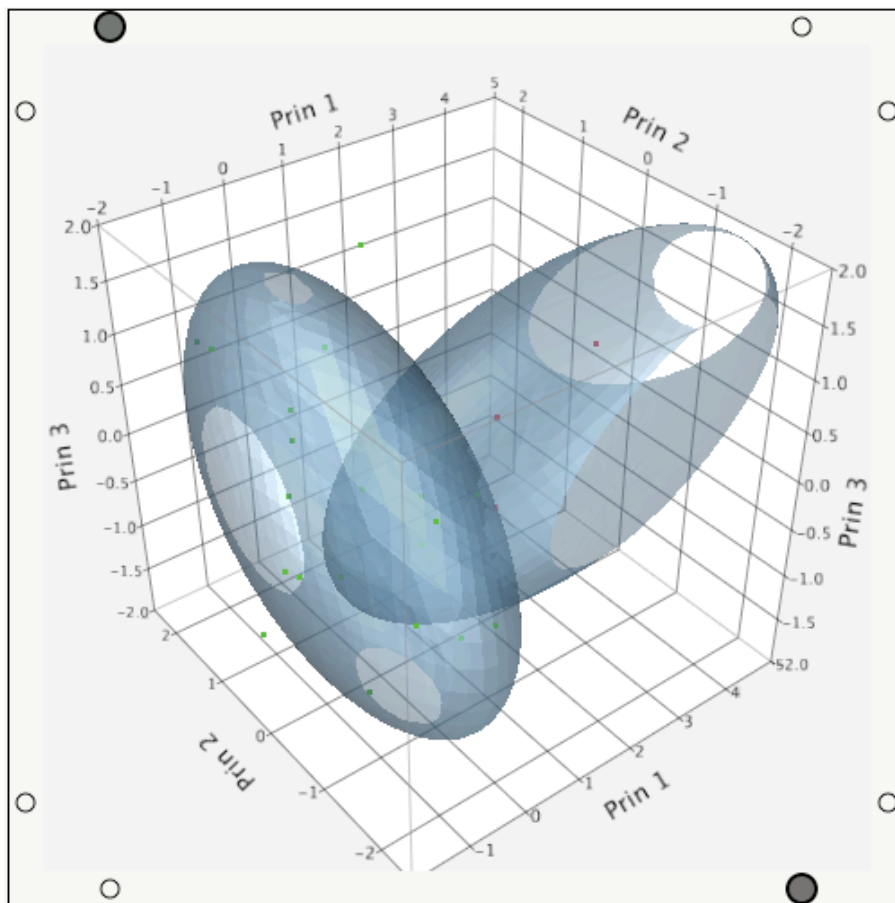


Figure 41: Results of clustering for the scaled reaching above the shoulder task. Each sphere represents a grouping of participants based on the ranges of plane of elevation, angle of elevation and humeral rotation, mean velocity and mean moment. Each dot represents a participant.

8.0 Discussion

8.1 Addressing Specific Aims and Hypothesis

Hypothesis 1

It was hypothesized that active range of motion would be reduced in the impaired elderly population when compared to the mobile elderly population in internal and external rotation only. The range of internal/external rotation was found to be lower between the two study populations. However significant differences between the two populations were also found for the range of flexion/extension and abduction. Hypothesis 1 was not supported by the results of this investigation.

Hypothesis 2

It was hypothesized that different identifiable movement strategies would exist between the elderly mobile and elderly impaired population. The results of the k-means clustering analysis did not show clear differences in movement strategies. An analysis of variance with injury status and task as factors revealed that differences between impairment and mobile populations only existed for some of the variables of interest; mean range of angle of elevation, mean range of humeral rotation and mean resultant external shoulder moment. Few differences in time series motion patterns were seen between the two populations. Hypothesis 2 was not supported by the results of this investigation.

Hypothesis 3

It was hypothesized that different tasks would require different ranges of motion. Task was a significant main effect for each of the mean ranges of motion; plane of

elevation, angle of elevation and humeral rotation. Overall, hair-combing, perineal care and the reaching tasks were the most demanding tasks. Hypothesis 3 was supported by the results of this investigation

The specific aims of this study were to identify kinematic differences between elderly mobile and impinged individuals during activities of daily living, quantify resultant external shoulder moments during specific activities of daily living, quantify any differences in shoulder range of motion between mobile and impinged seniors and to link these differences to mechanistic movement adaptations, if any existed.

Identification of kinematic differences between elderly mobile and impinged individuals during activities of daily living

By using the Vicon motion capture system, position data of the upper limb and trunk during specific activities of daily living in elderly mobile individuals, as well as elderly individuals with symptomatic rotator cuff impingements were collected. Euler angles of the humerus were calculated based on the position data. Statistical analysis of the angles calculated for each task showed that not all angles were significantly different between elderly mobile individuals and elderly individuals with symptomatic rotator cuff impingements.

Quantification of external shoulder moments during specific activities of daily living

The Shoulder Loading Analysis Modules were used to calculate shoulder moments for each specific activity of daily living from the position data. Average moments were calculated for each population and for each ADL.

Identification of differences in shoulder range of motion between elderly mobile individuals and elderly individuals with rotator cuff impingements

Position data was collected from a senior mobile and senior impinged population. From this data Euler angles were calculated and peak angles were identified for each ROM task. The two populations showed significant differences for three of the five ROM tasks.

Link these differences between the two populations by describing mechanistic movement adaptations during activities of daily living, if any exist

Few differences were noted between the studied populations during the ADL tasks. K-means clustering techniques were used to attempt to categorize the participants into mobile and impinged populations based on the angles, moments, velocities and objective functions collected. This had very limited success.

8.2 Quantification of the Effect of Rotator Cuff Impingements on Range of Motion

Peak flexion/abduction angles found in this study were smaller than those found in previous investigations with abduction angles of elevation of $140 \pm 20^\circ$ for the mobile

group and $96 \pm 30^\circ$ for the impinged group and flexion angles of $145 \pm 24^\circ$ and $108 \pm 28^\circ$ for the mobile and impinged groups respectively. Chakravarty and Webley (1992) reported mobile flexion/abduction angles (measured with a goniometer) of $174 \pm 4.9^\circ$ and mean angles of $123 \pm 18.6^\circ$ and $112 \pm 9.2^\circ$ for individuals aged 65-74 with shoulder disorders (mean age of 68.7 years) and 75 and older with shoulder disorders (mean age of 78.36 years) respectively. Baydar *et al.* (2009) also saw higher flexion and abduction angles (measure with a goniometer) in patients with full-thickness rotator cuff tears (confirmed by magnetic resonance imaging) than were found in the impingement group in the current investigation. Baydar *et al.* (2009) reported flexion and abduction angles of $139.3 \pm 23.8^\circ$ and $132.7 \pm 31.6^\circ$ respectively in participants with a mean age of 60.9 ± 7.7 years. Some discrepancies between the current investigation and the above studies may be attributed to the use of a goniometer to measure the abduction and flexion angles as opposed to the Euler angle approach used in the current study. Both the Chakravarty and Webley (1992) and Baydar (2009) study used participants that were still functioning in their own homes and had not moved to an assisted living environment. It is possible that since there is a reduced need for those in an assisted living environment to accomplish tasks independently, the reduction in flexion and abduction angles seen in this study could be partially due to reduced strength (Bauer, 2008). An alternative explanation for the decreased range of motion seen in the current investigation is that there is a difference in ages of the participants involved in each study. Chakravarty and Webley (1992) found that range of motion decreased with increasing age. The average age of the participants was higher in the current study (83 ± 6 years) than seen in previous studies (Chakravarty and Webley, 1992, Baydar *et al.*, 2009). Chakravarty and

Webley (1992) used participants from two age groups one with a mean age of 68.7 years and the other with a mean age of 78.4 years. Baydar *et al.* (2009) studied a population with a mean age of 60.9 years. This age difference could have some involvement in the decreased abduction and flexion angles.

Internal rotation values in the current study were smaller than those found in Magermans *et al.* (2005) who studied populations after implantation of an endoprosthesis.

Magermans *et al.* (2005) reported internal rotations of $56.6 \pm 20.1^\circ$ while the current investigation found internal rotations of only $5 \pm 24^\circ$ for the mobile population and $-8 \pm 12^\circ$ for the impingement population. External rotations were reported to be $-79.1 \pm 14.3^\circ$ while this study found that the mobile population had an average of $-107 \pm 22^\circ$ and the impinged population had an average of $-76 \pm 27^\circ$, similar to those found in Magermans *et al.* (2005). The way in which the rotations were measured differed between the two studies. Magermans *et al.* (2005) measured rotations with the humerus abducted to 90° degrees while the current study only abducted to 45° because some of the impinged population was not comfortable abducting to 90° . It is therefore important to also compare the ranges of internal/external rotation between the studies. The participants in Magermans *et al.* (2005) had an internal/external rotation range of 135.7° while the healthy population in the current investigation had a smaller range of $112 \pm 41^\circ$. The injured population had an even smaller range of only $67 \pm 24^\circ$. The differences in ranges seen between the Magermans *et al.* (2005) and the populations in the current investigation could be attributed to age as age has been shown to be related to decreased shoulder range of motion (Charkravary and Webley, 1992). Participants in Magermans *et*

al. (2005) had a mean age of 36.8 +/- 11.8 years while the current study examined participants with a mean age of (83 +/- 6 years).

Previous investigations of shoulder range of motion suggest that populations with signs of rotator cuff impingement or tears have decreased capabilities in internal and external rotation (van Andel *et al.*, 2008, Senbursa *et al.*, 2007) and little differences in abduction and flexion (van Andel *et al.*, 2008, Baydar *et al.*, 2009, Kilintberg *et al.*, 2008). The findings of this study did not agree with previous literature as significant differences were found between the elderly mobile and elderly impingement population's range of motion in flexion/extension, abduction and internal/external rotation. However these studies were dealing with younger populations that were not being assisted with their daily tasks. It is possible that increased age and increased dependency on others has cause muscle weakening of all the shoulder muscles rather than just the rotator cuff muscles (Bauer *et al.*, 2008). This possible decrease in strength of the shoulder could be responsible for the decreased range of motion seen in the flexion and abduction angles.

8.3 Quantification of the Effect of Rotator Cuff Impingements on Activities of Daily Living

Euler Angles

A main effect of injury status was present for both range of angle of elevation and range of humeral rotation. For both variables, the elderly mobile population used a greater range of motion than the elderly impingement population. This may indicate that the impingement population has found ways to complete the tasks using a smaller range of motion. There was no significant effect of injury status on range of plane of elevation,

demonstrating that angle of elevation and humeral rotations are the largest movement challenges faced by elderly populations with rotator cuff impingements. It should be noted that in this task, two of the impinged population were unable to complete the reaches and were included in the analysis to provide useful information that could be used to modify their living environments.

An injury status by task interaction term was present for range of angle of elevation. The mobile populations used significantly larger ranges of angle of elevation for tasks that required large angles of elevation (hair combing, scaled reach and reach). For example the impingement population range for the scaled reach and reach task was 55% and 67% lower than the mobile population. This signifies that shelving and cupboards should be lowered for elderly patients suffering with impingements in order to help them remain independent. The impingement population's smaller range of motion for the hair-combing task is representative of a movement adaptation as all participants were able to complete this task. From observation of the participants, it was noticed that nearly all impingement participants tended to rotate and lower their head in order to complete the hair combing on the back and left side of their head, whereas the mobile population tended to reach their arm over their head. This movement adaptation could be taught to other elderly patients in order to ease their pain when combing their hair.

The angles required to complete the ADL tasks were similar between the two populations, however the amount of movement needed to complete each task did vary. The eating with a spoon task and the washing the axilla task did not require full range of

motion in any of the 3 planes and were completed by all participants in both study groups. The perineal care task required the most extreme mean range of plane of elevation as it required movement in the negative direction (rotation about the vertical axis towards the participants back) with mean range of 103 +/- 28. The hair-combing task was the second most demanding of range of plane of elevation and required a range of 36 +/- 21. This was required to reach the left side of the head. The hair-combing task, along with the two reaching tasks, also demanded the largest range of angle of elevation and was second to perineal care in terms of the demand for a large range of humeral rotation. This signifies that perineal care and hair combing are the tasks demanding the largest range of motion of the shoulder. These two activities, along with the reaching tasks, should be considered a priority when developing adaptive strategies for those living with rotator cuff impingements.

External resultant shoulder Moments

External resultant shoulder moments did not vary much in terms of magnitude or variability between populations. This indicates that reduction of shoulder moment is apparently not a primary mechanistic goal of compensatory movement that may occur in an impinged population.

The evaluation of external resultant shoulder moments did reveal a main effect of task. Shoulder joint moments are known to increase with increased reach distance and increased shoulder flexion angle (Giroux & Lamontagne, 1992; Anton *et al.*, 2001). Consequently, it is not surprising that the two reaching tasks (both reach and scaled

reach) were found to have the highest moments followed by the hair-combing task. This is further evidence that these tasks should be considered a priority when developing adaptive moment strategies or developing changes in living environments.

Velocity

The task being performed showed to have a significant effect on the velocity with which the task was performed. Tasks that required larger ranges of motion (reach, scaled reach and perineal care) had significantly higher velocities than all other tasks. It is possible that these tasks are performed faster in order to reduce the time in extreme positions, either for strength or pain purposes or may be related to the total excursion as these were the tasks that required some of the largest movements. In the case of perineal care, there may have been some psychosocial motivation to move their hand from the area of the perineum quite quickly. Eating with a spoon and hair combing were the tasks that were completed with the lowest velocities. Both of these tasks required some precision, which may have been the cause of the reduced velocity.

There was no difference in velocity between the mobile and impingement populations. Roy *et al.* (2009) suggested that increased velocity could increase the risk of subacromial impingement. It is possible that teaching the elderly impingement group to perform tasks slower could provide a compensatory strategy to increase glenohumeral stability and reduce pain.

Objective function

Variability of the objective function in the impingement population was very high in comparison to the mobile populations, as demonstrated from the high standard deviation (table 10). The high standard deviations could be responsible for the lack of statistical significance. Since no imaging techniques were used to determine the presence of rotator cuff impingements, it is possible that there was a wide range of severity of injury within the impingement group. With increased tear size there is increased instability of the glenohumeral joint (Hus *et al.*, 1997). It is therefore possible that the potential variability in impairment severity resulted in different movement patterns that were responsible for the high variability in this output measure.

Time series data

The time series data further emphasized which tasks showed the most movement differences between the populations. Few differences were noted between the populations during washing the axilla and eating with a spoon, while differences in Euler angle patterns or standard deviations were noted between the two populations for the two reaching task, as well as the hair-combing and perineal care tasks. Increased standard deviation for plane of elevation in the mobile population during the hair combing task may indicated that the mobile population adapted several different techniques in order to complete the ADL, while the tight standard deviation for the impingement population may indicated that they have all completed the task in a similar manner. Perhaps this is a specific movement adaptation that has made hair-combing easier for this population. The

impingement population had visually larger standard deviations in angle of elevation and humeral rotations for the perineal care task. This task demanded a larger amount of humeral rotation and an angle of elevation with a negative slope (meaning the participant had to reach backward), which may have provided some challenges for the impingement population. It is possible that the large standard deviation seen can be attributed to a variety of movement adaptations made by the impingement population in order to make the task easier. An alternative explanation is that the impingement population may have had a wide range of severity of injury and therefore a wide range of movement patterns. Both reaching tasks visually showed a higher peak angle of elevation for the mobile population, which is indicative of the impinged population's difficulty with this task. This is further evidence that the reaching and perineal care tasks require the impingement population to adapt their movement patterns and should be considered a priority in developing movement or environment adaptations to help impingement populations with ADLs.

Clustering techniques

The literature suggests that compensatory movement strategies may exist in impaired populations (Roy *et al.*, 2009) in both joint angles and muscle activation (Myers *et al.*, 2009). The results of the k-means clusters in this study were not able to routinely discriminate between the mobile and impinged populations. This does not necessarily indicate that compensatory strategies do not exist, but that it was not possible to capture any by looking at Euler angles, external resultant shoulder moments, velocity and objective function. Perhaps more success would come from looking at the activity of

individual muscles as the high variability in the impingement group compared to the mobile group indicates that some differences may be present in individual muscle activations.

Reach above shoulder height and scaled reach

The participants in this study completed two different reaches. The first reach height was representative of an average shelf height and the second reach was scaled to 80 percent of reach capability. All mobile participants were able to complete both reaches, however only 80 percent of the impingement population were able to complete both reaches. The reduction to 80 percent of reach capacity was not sufficient to allow all of the impingement population to complete the task. This could have applications in the design of more functional living spaces for those living with rotator cuff impingements.

8.4 Limitations

This investigation examined the effect of rotator cuff impingements in an elderly population in an assisted living environment. Common tests used in physical therapy were used to identify patients with symptomatic rotator cuff tears. The tests could not determine the severity of a tear in the impingement population, which may have led to the high variability in the objective function values of the impingement group. Similar difficulty in isolating individual muscular contributions to performing tasks has been noted before for manual muscle tests common in physiotherapy (Brookham *et al.*, in press). Access to imaging equipment and technologists could have helped to categorize

the severity of the rotator cuff injury in the impingement and exclude people with asymptotic tears from the mobile population.

Although all participants did not have any diagnosed cognitive impairments or joint diseases, it is possible that some may have had undiagnosed conditions other than rotator cuff impairments (such as arthritis) that could have altered the movement patterns (Moskowiz, 2009, Ahn *et al.*, 2009)

Motion patterns of the right arm and trunk were collected during this investigation. Only the kinematics of the right humerus with respect to the torso was considered. It is possible that the analysis of the head, right forearm and hand and left upper limb could give insight into movement adaptations, especially in the impingement population.

The use of surface EMG techniques was not possible for the elderly population, as the effect of skin movement would cause substantial error in the data. Indwelling EMG could not be used, as it is too invasive for the elderly and can cause risk of infection that can be a large health problem in a senior population. As a result, this study estimated muscle activity using a biomechanical model. Since the shoulder is an indeterminate system, the model uses an objective function that minimizes the sum of the cubed muscle stresses to determine a unique solution. It has not been proven that the body distributes loads to the muscles in this manner in all loading conditions; therefore there is possibility for error in obtaining the objective function in this fashion. The model has shown to yield reasonable results when compared to results obtained by use of EMG, however this

was for load transfer tasks throughout the right-hand reach envelope and used university aged participants (Dickerson *et al.*, 2008). The use of this model for prediction of muscular effort in activities of daily living or its use in an elderly population has not been validated.

The model was not adjusted to reflect a decrease in rotator cuff strength when calculating the objective function of the impingement population. Magermans (2000) adjusted a biomechanical model to account for rotator cuff tears and found that glenohumeral stability was compromised as a result. A study by Roy *et al.* (2009) demonstrated that there was increased rotator cuff muscle co-activation and deltoid activation during humeral elevation in a population with rotator cuff impingements when compared to a mobile population. Further studies on cadavers indicate that the rotator cuff provided substantial stability to the glenohumeral joint only in mid and end ranges of motion (Lee *et al.* (2000). The activities of daily living performed in the current investigation involved a large range of motion including the low range. Perhaps an adjustment of the model to account for the effect of the rotator cuff impingement could lead to more insight into the muscle activation necessary for this population to stabilize their glenohumeral joint during activities of daily living.

8.5 Suggestions for Future Research

Future investigations could directly address the limitations of this study, investigate different populations and design changes to the living arrangements of those living with rotator cuff impairments.

A similar study that allowed for imaging to diagnose various stages of rotator cuff impairments may lead to more insight in to what level of injury is necessary to identify compensatory strategies, if any exist, and determine if different compensatory strategies are present at different levels of impairment. This would also help establish how range of motion and ability to complete ADLs varies with severity of injury. The inclusion of a medical doctor or physical therapist in this study would be helpful in insuring no other musculoskeletal or neurological conditions are present.

An investigation that took the right forearm, hand, left upper limb and head kinematics into consideration may give more insight into the movement adaptation strategies adopted by elderly populations suffering with rotator cuff impingements.

The model has not been validated for use in muscle estimation for activities of daily living in any population. Future investigations could examine the validity of this model in ADL tasks by collecting EMG as well as kinematic data. Although EMG has its limitations in an elderly population, the use of middle aged and young participants could give insight into the effectiveness of the model and into the effect of age on the models ability to predict muscle forces.

Further investigations into individual muscle forces would be helpful in determining if different muscle activation levels and patterns exist between an elderly impinged population and an elderly mobile population. It is possible that the additional information

on specific muscle activity could be used in clustering analysis in an attempt to improve the recognition of the two populations. This could give us more insight into how those suffering with rotator cuff impingements compensate in their activities of daily living at the individual or group muscle level.

The examination of various populations could give more insight into the mechanisms of coping with rotator cuff tears and may help tease out if there were any effects of muscle wasting and decreased strength of all shoulder muscles as opposed to just the effects of a rotator cuff tear. Other potential populations would include a young or middle-aged population or a senior population that is still living independently.

Further investigation into the comfort level of those suffering with rotator cuff impairments while performing ADLs, especially reaches, may help in determining appropriate modifications to living environments to help reduce pain associated with these tasks.

9.0 Conclusions

In identifying differences in range of motion and kinematics of ADLs between an elderly mobile and elderly population with rotator cuff impingements, this investigation yielded two main conclusions based on the specific aims and hypotheses:

- Shoulder range of motion is decreased in elderly populations with rotator cuff impingements when compared with a mobile elderly population in abduction, flexion and external rotation.
- Mechanistic differences in movement strategies were not consistently identifiable between an elderly mobile population and an elderly population with rotator cuff impingements using range of Euler angles, resultant external shoulder moments, humeral velocities and objective functions.

The current investigation was able to quantify the humeral angles and moments necessary to complete 6 selected activities of daily living. Activities that required large ranges of motion were identified as reaching above shoulder height, a scaled reach, perineal care and hair-combing tasks. The two reaching tasks were the only tasks that some participants were not able to complete, as they did not have the necessary angle of elevation range of motion.

Large variability was seen in the objective functions of the impingement group across all ADLs. It is possible that this could be partly due to a potentially large variability in injury severity or specific injury type.

Applications in a clinical environment

This investigation showed that developing adaptations for perineal care, hair-combing and reaching tasks should be considered a priority when working with patients with rotator cuff impingements, as these tasks demanded the largest ranges of motion as well as high shoulder moments.

Applications in design of living environments

The range of motion of an elderly population is reduced in comparison to younger populations with elderly impinged populations showing even further reductions in range of motion. This study has quantified the active range of motions of which these populations are capable. The design of living environments that are more conducive to the reduced ranges of motion seen in both populations investigated in this study could be based off of the findings of this study. Simple changes such as lowering shelves to accommodate the reduced ranges could ease the day-to-day burden experienced in these populations and help keep them living as independently as possible.

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Appendix A: Information and Consent Form

Project Title: Analysis of effect of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living

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Purpose of the Research

Despite a large prevalence of shoulder pain in senior populations, little research has focused on understanding how people experiencing this pain adapt to perform tasks of daily living. The purpose of this research is to identify movement differences between senior mobile individuals and senior individuals with shoulder pain during specific activities of daily living by determining rotational forces at the shoulder and using a computer model to estimate how the muscles are working. If it is possible to determine how those living with shoulder pain manage to complete activities of daily living, then it may be possible to keep seniors with these types of injuries living more comfortably and independently.

Study Participants

Thirty right hand dominant participants will be recruited from a senior population living in The Village of Winston Park or the Village of Riverside Glen Retirement Residences, and will range in age from 65-100 years. Fifteen of these participants will represent an elderly population who will exhibit no signs of shoulder pain as determined by 2 movement tasks (The Hawkins and painful arc tests). The results of these tasks will be used to guide entry into the study. These participants will have no history of shoulder pain or injury in the past six months. The remaining 15 participants will test positive for shoulder pain as determined by 2 movement tasks used to guide entry into the study.

Exclusion criteria will include

Upper limb or back injury (excluding shoulder pain) within the past six months

Diagnosed cognitive impairments (Alzheimer's disease or dementia-Participant must be able to provide their own consent to participate)

Screening Procedures

A screening process will occur prior to data collection to determine if you show signs of shoulder injury. You will be considered show signs of shoulder injury if you test positive in two common physiotherapy tests. In the first test you will be asked to slowly raise your arm from your side and to report if any portion of the abduction is painful. If pain is reported between 60-120°, then the test will be considered positive for pain. This test is not intended to induce pain but rather if you feel discomfort during the test you will be asked to stop and will be given a positive score on the test. Upon completion of this test, the Hopkins test will be preformed. You will be asked bring your arm forward to 90° and then we will gently guide the rotation of your arm toward the centre of your body. If this is painful, the test is considered positive for pain. Once again the test will stop once you indicate any discomfort.

Study Procedures

You will have 19 reflective spheres will be placed on their right arm and torso using medical tape. You will be asked to perform five active shoulder range of motion tasks including raising your arm forward, backward, sideways and rotating your arm toward and away from your body. Each task will be repeated 3 times. You will then be asked to perform six tasks of daily living outlined in the following;

i) Eat with a spoon task

You will be asked to pick up a spoon from table height (66cm) bring the spoon to your mouth and then return the spoon to the table.

ii) Combing hair task

You will be asked to start with your right hand holding a comb and resting on the table then bring your hand to the right side of the crown of the head, the backside of the crown of your head and the left side of your head before returning your hand to the table. One stroke of the comb will be completed at each of the 3 locations on the head. A new comb will be provided for each participant.

iii) Washing the under arm task

You will be asked to start with your right hand resting on the table and then asked to bring your right hand to the left underarm before returning your hand to the table.

iv) Reaching above the shoulder task

This task will begin with your right hand resting on the table. You will then be asked to reach to a target located 1.5 m off the ground and centered in front of your body. This task would simulate putting something away on a shelf.

v) Reaching above the shoulder-scaled to torso height

Prior to the beginning of the collection, the researcher will measure the distance from your hip to the tip of your fingers (with your hand raised high). This task will begin with your right hand resting on the table. You will then be asked to bring your right hand to a target located at 80% of the measured distance plus the height of the chair (43 cm).

vi) Perineal Care

From a seated position with your right hand resting on the table, the participant will be asked to bring their hand to their to a point on their back just above the chair. This motion is comparable to personal care after going to the washroom.

Following the task you will be asked to give an oral rating of the discomfort you felt during the tasks on a scale of zero to ten. Zero will represent no discomfort while ten will represent extreme discomfort.

Potential Harms

There are a few risks associated with this study, similar to risks you would experience in your daily living. If you have known allergies to medical tape please inform the researcher. Some temporary discomfort may occur during screening tasks but should disappear immediately following the test.

Potential Benefits

There are no financial benefits. You will learn about current scientific research techniques and about your own shoulder capabilities. The results of this study will help guide new methods to help physiotherapists or rehabilitation therapists teach people with shoulder pain ways to accomplish tasks of daily living without pain.

Confidentiality and Security of Data

As a participant, you will be given a three letter, single number code that will be used to distinguish each participant but still maintain anonymity. Confidentiality will be respected. No information that discloses your identity will be released or published in any report without your specific consent to the disclosure. Information from all participants, including yourself, will be combined together in a secure location (Dr Dickerson's research lab at the University of Waterloo). All data will be stored on computers, in locked offices and laboratories. All computers used are password protected. Paper and electronic data will be stored indefinitely in Dr. Dickerson's research lab.

Participation and Withdrawal from the Study

Participation in this research is voluntary. You can say no and stop the research at any time. If you choose not to participate, before during or after the study, you will not be penalized in any way or be unable to participate in future studies with the University of Waterloo or at Winston Park or Riverside Glen and it will not have any effect on your relationship with The Village of Winston Park or The Village of Riverside Glen.

Time Commitment

The study will require 2 sessions. The first will be approximately 10 minutes long and will consist of the researcher performing 2 screening tests in order to guide entry into the study. The second session will be approximately 1 hour long and will consist of performing several activities of daily living.

Study Inquires

If you have any questions regarding the study or your participation in the study please contact Dr. Clark Dickerson at 519-888-4567 ext. 37844.

Concerns about Your Participation I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics. If you have any comments or concerns resulting from your participation in this study, you may contact Dr. Susan Sykes, Director ORE, at (519) 888-4567 ext. 36005.

Consent to Participate in Research

I agree to take part in a research study being conducted by Dr. Clark Dickerson and Laurie Hall of the Department of Kinesiology at the University of Waterloo.

I am aware of what will be taking place during the research and have had any questions answered with regards to the study. I understand that I may withdraw from the study at any time without penalty by telling the researcher. I am aware that my withdrawal from the study will have no effect on my relationship with the University of Waterloo or with The Village of Winston Park and will have no effect on my eligibility to participate in studies run by either institution in the future.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I can contact Susan Sykes, Director, Office of Research Ethics at (519) 888-4567 ext. 36005.

Participant Signature

Participant Name

Date

Witness Signature

Witness Name

Consent to Use Digital Images in Teaching, Presentations, and Publications

Sometimes a certain images clearly show a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I agree to allow digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name and that any facial features will not be discernible.

I am aware that I may withdraw this consent at any time without penalty. If consent is withdrawn, I ask that all digital images of myself be erased and removed from storage. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Dr. Susan Sykes, Director, Office of Research Ethics, at: 519-888-4567 ext. 36005.

Print Name: _____

Signature of Participant _____

Date: _____

Witnessed _____