Test-retest reliability of shoulder functional characteristics using measures from the Simulator II in a healthy adult population of women

By

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ABSTRACT

Shoulder Musculoskeletal Disorders (MSDs) are prevalent conditions particularly among women. Obtaining accurate measurements of shoulder range of motion (ROM) is a major concern for the clinical setting. The purpose of this project was to obtain reference data and assess test-retest reliability of shoulder ROM using the BTE simulator II (Simulator II, BTE technologies™) in a healthy adult population of women. Shoulder ROM was assessed from thirty female right-handed subjects (20-52 years old) in flexion, extension, external rotation and abduction, on two separate days. ROM measurements were slightly different from those of the literature, were not associated with age or anthropometric characteristics, similar between left and right sides except for abduction, and independent from handedness scores. Test-retest reliability was moderate to excellent (above 0.77 for almost all movements and 0.56-0.73 for external rotation). Standard error of measurement and minimal detectable change were smaller than values reported for goniometric measurements. Patient studies are needed to implement the Simulator II in clinical settings.

RÉSUMÉ

Les blessures musculo-squelettiques de l'épaule représentent une condition répandue chez les femmes. Obtenir des valeurs précises d'amplitude de l'épaule est une priorité en clinique. Le but de ce projet était d'obtenir des valeurs de références et d'évaluer la fidélité test-retest des amplitudes de l'épaule en utilisant le "BTE simulator II (Simulator II, BTE technologies™)" sur une population de femmes en santé. Les amplitudes de l'épaule ont été mesurées chez trente sujets droitières (âgées de 20-52 ans) en flexion, extension, rotation externe et abduction, à deux jours différents. Les amplitudes avaient quelques différences avec celles de la littérature, n'étaient pas associées aux mesures démographiques ou anthropométriques, étaient similaires entre les côtés gauche et droit sauf pour l'abduction, et étaient indépendantes des scores de latéralité. La fidélité test-retest était modérée à excellente (supérieure à 0,77 pour presque tous les mouvements et entre 0,56-0,73 pour la rotation externe). L'erreur standard et le changement minimum détectable étaient plus petits que ceux rapportés pour des mesures goniométriques. D'autres études sont recommandées pour l'implantation du "Simulator II" dans le milieu clinique.

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CHAPTER 1 - INTRODUCTION

Musculoskeletal disorders (MSDs) are a major problem in industrialized societies; their economic impact on workplaces, as well as for the society, is evident (Melhorn, 1998; Palsson et al., 1998). MSDs can affect muscles, tendons, ligaments, and joints of the human body. This problem has only grown in size in the last few decades. In 1990, 15% of the entire working population in the United States suffered from one or more types of chronic MSDs, and this rate is anticipated to increase to 18% within the next 30 years (Lawrence et al., 1998). For the health care industry, 73% of all compensable claims between 1994 and 1998 resulted from MSDs (WCB, 2000). However, ergonomic interventions have shown little success in improving musculoskeletal health among the working population (Westgaard and Winkel, 1997). During the past decade, upper extremity musculoskeletal disorders (UEMSD) have become one of the most significant and costly health problems among the worldwide working population (Feuerstein et al., 1998; Silverstein et al., 1998; Muggleton et al., 1999). UEMSDs are painful conditions affecting soft tissues of the hands, arms, shoulders, and neck (Mani and Gerr, 2000). The prevalence of work-related UEMSDs reported in the United States has increased dramatically during the past two decades; in 1982, they accounted for 18% of all reported occupational illness and in 2002, they accounted for two thirds (US Bureau of Labor Statistics, 2003).

Recent studies suggest that physical risk factors associated with shoulder complaints and disorders can be related to monotonous repetitive movements, forceful exertions, awkward postures, static contractions and vibration of the neck / shoulder and upper extremities at the workstation (Berlin and Vermette, 1985; Bear-Lehman and Abreu, 1989; Keyserling, 2000; Reesink et al., 2007). Injuries and disorders caused by overexertion and repetitive motion are the leading causes of compensable lost-time cases in the United States (Keyserling, 2000).

The shoulder girdle (bones set which bring together, the upper limb and the axial skeleton) is light and allows the upper limbs a degree of mobility not seen anywhere else in the body (Marieb and Hoehn, 2009). The shoulder girdle is also an important part of the shoulder joint (segment of the body where the humerus bones attaches to the scapula) and arm movements depend on its adequate range of motion (ROM) (Nadeau et al., 2007). ROM assessment has long been recognized as an important part of the shoulder musculoskeletal examination (Awan et al., 2002). ROM is oftentimes used to assess joint mobility, determine disability impairment, establish a diagnostic, monitor treatment effects, document improvements in mobility and set realistic goals for patients (Moore, 1949; Walker et al., 1984; Greene and Heckman, 1994; Hayes et al., 2001; Nadeau et al., 2007). Clinical decisions are oftentimes based in part on these data (Greene and Wolf, 1989; Awan et al., 2002). The assessment of shoulder ROM is particularly important in the diagnosis of disorders of the shoulder and for the evaluation of the strategies that may alter proper shoulder function (Nadeau et al., 2007).

Several studies have reported measurements of shoulder ROM made with goniometers and other related systems. In general, no studies have reported significant differences in ROM between the dominant and non-dominant shoulders, although no studies assessed the relationship between shoulder ROM and handedness (the degree of dominance of the use of one side compared to the other). In addition, although the prevalence of work-related shoulder MSDs is higher among women and most studies indicate that ROM may be greater in women compared to men, most have assessed shoulder ROM in gender-balanced subject samples and none has reported psychometric properties of ROM measurements taken in a sample of women. Finally, even though very young and very old age have been shown to affect shoulder ROM, the relationships between shoulder ROM and characteristics such as age in adulthood, height, weight and arm segment lengths are not well known.

The Baltimore Therapeutic Equipment (BTE) Work Simulator II (from the BTE technologies™, Hanover, Maryland) is a commercial system equipped with potentiometers and load cells that allows the measurements of force and motion. The Simulator II appears to be the most thoroughly researched instrument for work simulations, with test-retest, intra-test and instrument reliability investigated in healthy and injured populations (Innes and Straker, 1999); however, only a limited number of the Simulator II's 22 attachments have been tested (Trossman et al., 1990; Coleman et al., 1996). The Simulator II is simple to use, doesn't depend on manual guidance from the clinician, and provides objective data that is available quickly to the clinician and to the patient, making it a system of choice in the clinical setting (Kennedy and Bhambhani, 1991). Although the Simulator II can be used to measure shoulder ROM as well as work-related performance, its psychometric properties in measuring shoulder ROM have never been reported.

The objectives of this study were to document reference values of shoulder range of motion in four different movements in a healthy right-handed group of women using the Simulator II system. We also wanted to verify whether these measurements were associated with age or anthropometric characteristics of subjects, assess the test-retest properties of the apparatus in measuring shoulder ROM as well as to compare ROM values across shoulders (dominant and non-dominant). This project was an essential first step to a second study in which the candidate participated as co-author of a book chapter, which ultimately aims to compare shoulder ROM between groups of healthy subjects and patients with neck-shoulder pain (Lomond et al., 2009).

CHAPTER 2 - LITERATURE REVIEW

On the basis of the current literature and the various tasks and attachments provided by the system, the reliability and validity of the BTE simulator II (Simulator II) has not been well demonstrated at this time, and should therefore not be entirely relied on as an accurate assessment instrument. It is evident that more research studies designed to test psychometric properties of the Simulator II are needed (Kennedy and Bhambhani, 1991), so as to insure adequate use in the clinical and rehabilitation world. Below is a summary of the literature pertinent to the present project.

2.1 Why measure shoulder function?

2.1.1 Prevalence of Musculoskeletal Disorders (MSDs)

MSDs are a major problem in industrialized societies; their economic impact on workplaces, as well as for the society, is evident (Melhorn, 1998; Palsson et al., 1998). MSDs can affect muscles, tendons, ligaments, and joints of the human body. They are the cause of common complaints in both the general and working populations (Treaster and Burr, 2004) and they are the main cause of sickness absence and disability pensions (Synnerholm, 1995; Leijon et al., 1998; Persson et al., 2001). This problem has only grown in size in the last few decades. For instance, sickness absence due to neck / shoulder and low-back disorders has increased continuously between 1986 and 1994 in Sweden (Leijon et al., 1998). In 1990, 15% of the entire working population in the United States suffered from one or more types of chronic MSDs, and this rate is anticipated to increase to 18% within the next 30 years (Lawrence et al., 1998). In the province of British Columbia, Canada, a major concern in the health care industry is the escalating incidence, duration and costs of compensation claims, absenteeism and medical expenses resulting from MSD (Russo et al., 2002). 73% of all compensable claims between 1994 and 1998 resulted from MSD, and the direct cost for these claims was estimated at $113.4 million (WCB, 2000). The cost figures are just as staggering in the USA (NIOSH, 1997) and European countries (European Agency for Safety and Health of Work, 1999). However, ergonomic interventions have shown little success in improving musculoskeletal health among the working population (Westgaard and Winkel, 1997).

2.1.2 Shoulder MSDs

During the past decade, upper extremity musculoskeletal disorders (UEMSD) have become one of the most significant and costly health problems among the worldwide working population (Feuerstein et al., 1998; Silverstein et al., 1998; Muggleton et al., 1999). UEMSDs are painful conditions affecting soft tissues of the hands, arms, shoulders, and neck (Mani and Gerr, 2000). The literature has shown that UEMSDs can lead to particularly high rates of work disability, unemployment and insurance claims (Norlander et al., 1996). What is even more unfortunate is that the majority of these costs are not related to health care directly, but more due to sick leave, disability and loss of productivity (Borghouts et al., 1996). In the USA, the prevalence of reported work-related UEMSDs has impressively increased during the past 20 years. In 1982, they accounted for 18% of all reported occupational illness cases in the USA; in 2002, this number had increased to 66% (US Bureau of Labor Statistics, 2003). In 1994, 332,000 UEMSD cases involving lost workdays were reported to the US Bureau of Labor Statistics, an increase of 10% from 1993 (US Bureau of Labor Statistics, 1998). Furthermore, shoulder disorders have been specifically shown to have considerable impact on sickness absence (Nygren et al., 1995), utilisation of primary (van der Windt et al., 1995) and secondary (Vecchio et al., 1995; Vitale et al., 1999) health services, and premature withdrawal from the labour market (Lund, 2001). Although there is a belief that UEMSDs are under-reported, they are estimated to account for at least 4% of all state workers' compensation claims, an important increase from about 1% 10 years ago (Hales and Bernard, 1996; Bureau of Labor Statistics, 1997). Moreover, based on a single state's workers' compensation commission statistics (representing 8% of the US population), upper-extremity injuries represented between 21% and 23% of all reported compensable injuries, based on the known compensable musculoskeletal injury cases by body part for 5 years, from 1992 to 1996 (Texas Workers' Compensation Commission Annual Report, 1997). These reports also indicate that the average cost of an UEMSD case (total of medical and compensation costs) in 1992 was 80% higher than the average of all cases reported (Mayer et al., 1999). Since chronic disability leads to the highest cost, systematic evaluation of this growing occupational condition is needed (Mayer et al., 1999).

Many recent studies show that physical risk factors associated with shoulder complaints and disorders can be related to monotonous repetitive movements, forceful exertions, awkward postures, static contractions and vibration of the neck / shoulder and upper extremities at the workstation (Berlin and Vermette, 1985; Bear-Lehman and Abreu, 1989; Keyserling, 2000; Reesink et al., 2007). Injuries and disorders caused by overexertion and repetitive motion are the leading causes of compensable lost-time cases in the United States (Keyserling, 2000). These disorders often become chronic with highly negative consequences for the individual (Melhorn, 1998; Palsson et al., 1998). The prevalence of musculoskeletal disorders (MSDs) is thought to increase proportionally to the exposure to those risk factors (Keyserling, 2000).

2.1.3 Anatomical characteristics of the shoulder girdle

The human anatomy has evolved to become precise and efficient; the shoulder is one of the body's more unusual anatomical systems. The shoulder girdle is very light and allows the upper limbs a degree of mobility not seen anywhere else in the body. This mobility is due to the following factors (Marieb and Hoehn, 2009):

- Because only the clavicle attaches to the axial skeleton, the scapula can move with little restraint across the thorax, allowing the arm to move with it.

- The socket of the shoulder joint (the scapula's glenoid cavity) is shallow and weakly supported, thus it supplies little restriction of movement of the humerus (arm bone). The ball-and-socket shoulder joint is the most flexible joint in the body, but on the other hand, is one of the most unstable joints; shoulder dislocations are quite common.

The shoulder joint is made up of a bony structure that provides a pathway between the upper limbs and the trunk. These bones not only supply structure to the shoulder but also are attachment points for the shoulder muscles. Many muscles support this structure; allow movement and aid in stabilization. Shoulder muscles can be separated in two general groups: superficial muscles of the thorax for the movements of the scapula, and the ones crossing the shoulder joint (glenohumeral) for the movements of the arm (humerus). Most superficial thorax muscles run from the ribs and the vertebral column to the shoulder girdle, retaining the scapula in place and contributing to the range of arm movement. The principal movements of the pectoral girdle involve displacement of the scapula, i.e. its elevation, depression, rotation, lateral and medial movements. The clavicles rotate around their own axes to provide both stability and precision to scapular movements (Marieb and Hoehn, 2009). Finally, other anatomical structures such as the axilla region (brachial plexus nerve and lymph nodes) may be associated with UEMSD.

To provide active range of motion at the glenohumeral joint, several muscles cross each shoulder joint to insert on the humerus. All muscles acting on the humerus originate from the pectoral girdle; however, two of these (latissimus dorsi and pectoralis major) primarily originate from the axial skeleton. Of the nine principal muscles of the glenohumeral joint, only the pectoralis major, latissimus dorsi and deltoid muscles are prime movers of arm movements. The remaining six are synergists and fixators. Four of these, the supraspinatus, infraspinatus, teres minor and subscapularis are the rotator cuff muscles. They originate on the scapula, and their tendons blend with the fibrous capsule of the shoulder joint on the way to the humerus. Commonly speaking, muscles that originate anterior to the shoulder joint flex the shoulder and muscles originating posterior to the shoulder joint extend the shoulder. Located on the lateral side of the shoulder, the middle region of the deltoid muscle is the prime mover of arm abduction. Finally, the small muscles acting on the humerus promote lateral and medial rotation of the arm. The interactions among these nine muscles are complex and each contributes to several movements. Table 1 classifies the main shoulder muscles according to their location and their main action at the shoulder (Marieb and Hoehn, 2009).

Table 1 – Anatomical characteristics of the shoulder musculature

Name	Origin	Insertion	Action
1) Superficial muscles of the anterior and posterior thorax, movements of the scapula			
Pectoralis minor	Ribs 3-5	Coracoid process	Pull the scapula forward and downward
Serratus anterior	Ribs 1-8	Vertebral border of scapula	Rotate scapula
Subclavius	Rib 1 (Costal cartilage)	Clavicle	Stabilize and reduce the level of the scapula
Trapezius	Occipital bone, ligamentum nuchae, C7 and thoracic vertebrae	Acromion, scapula and clavicle	Stabilize and raises / retracts / rotates scapula
Levator scapulae	C1-C4	Scapula	Elevates / adducts scapula
Rhomboids	C7, T1 (minor) and T2 – T5 (major)	Scapula	Stabilize
2) Muscles crossing the shoulder joint, movements of the arm (humerus)			
Pectoralis major	Clavicle, sternum, Ribs 1-6 (or 7) and aponeurosis of external oblique muscle	Intertubercular sulcus (by a tendon) and humerus greater tubercle	Arm flexion (main muscle) / medial rotation / adducts arm
Deltoid	Hold Trapezius insertion, clavicle, acromion and scapula	Deltoid tuberosity of humerus	Arm abduction (main muscle)
Latissimus dorsi	Scapula, lower 6 thoracic vertebrae (via lumbodorsal fascia), lumber vertebrae, lower Ribs 3-4 and iliac crest	Teres major (around) and humerus intertubercular sulcus	Arm extension (main muscle) / adductor / medially rotation
Subscapularis	Scapula subscapular fossa	Humerus lesser tubercle	Medial rotator of humerus (main

			muscle)
Supraspinatus	Scapula supraspinatus fossa	Humerus greater tubercle	Originates abduction
Infraspinatus	Scapula infraspinatus fossa	Humerus greater tubercle (posterior) and supraspinatus	Rotates humerus laterally
Teres minor	Dorsal scapular surface	Humerus greater tubercle (inferior) and infraspinatus	Rotates humerus laterally
Teres major	Scapula (posterior surface)	Crest of lesser tubercle (anterior humerus) and latissimus dorsi (from a tendon)	Extends / Medially rotates / Adducts humerus
Coracobrachialis	Coracoid process of scapula	Humerus (medial surface)	Humerus flexion / adduction

2.2 Reference values of shoulder range of motion (ROM)

Measurements of joint motion are a concern of professionals in many disciplines; ROM is oftentimes used to assess joint mobility, determine disability impairment, establish a diagnostic, monitor treatment effects, document improvements in mobility and set realistic goals for patients (Moore, 1949; Walker et al., 1984; Greene and Heckman, 1994). Clinical decisions are oftentimes based in part on these data (Greene and Wolf, 1989; Awan et al., 2002). Indeed, objective assessment of muscle performance is an important aspect of the evaluation in the clinical setting. Information obtained through objective measures of ROM provides essential arguments to the clinician to determine functional status, planning a rehabilitation program and documenting effectiveness of surgical or therapeutic interventions (Leggin et al., 1996). Thus, standardization of valid and reliable methods of measurement is imperative when establishing the clinical usefulness of any proposed ROM measure (Awan et al., 2002).

A first aspect that should be considered is that a full range of motion of the upper limb requires motion of the scapula and the spine; it needs the alliance of glenohumeral (GH) and scapulothoracic (ST) joints movements (Crosbie et al., 2008). This is explained by the need of the humerus to link with the scapula to the trunk to achieve, for example, a full humerus-to-trunk scapular plane elevation (Crosbie et al., 2008; Yoshizaki et al., 2009). Moreover, some studies have highlighted a phenomenon called « scapular-humeral rhythm » which is known as the kinematic hallmark indicating motion of the shoulder joint (Yoshizaki et al., 2009). It helps to achieve further range of movement and those adjustments come from an imbalance in the muscles that maintain the scapula in place (trapezius). This inequality could cause a forward head carriage which in turn can affect the range of movements of the shoulder (Snell, 2006). As Yoshizaki et al. (2009) was concluding, the complementary actions of the GH and ST muscles are necessitated to provide the complex kinematics in the shoulder during some specific movements such as arm elevation and lowering.

The rotator cuff muscles of the shoulder produce a high tensile force, and help to pull the head of the humerus into the glenoid fossa.
Besides, the shoulder joint is an important part of the shoulder and arm movements depend on its adequate range of motion (Nadeau et al., 2007); compared to all the body joints, the shoulder has the greatest ROM (Hayes et al., 2001). As such, ROM assessment has long been recognized as an important part of the shoulder musculoskeletal examination (Awan et al., 2002); this constitutes an important step in the diagnosis of disorders of the shoulder (Hayes and al., 2001) and for the evaluation of strategies that may alter shoulder function (Hayes et al., 2001; Nadeau et al., 2007). An analysis of the literature on shoulder biomechanics was performed in order to collect values of shoulder ROM reported in previous studies (Table 2). Several studies have reported measurements of shoulder ROM made with goniometers and other related systems.

One of the first ones to do so was the Boone and Azen study (1979), in which authors measured active ROMs using a standard goniometer for several joints: shoulders, elbows, knee, hip, etc. The beginning and ending positions of each motion were measured once on the left and once on the right. Subjects were in a supine position for almost all shoulder measurements. Data was then qualitatively compared to a clinical database kept by the American Academy of Orthopaedic Surgeons (AAOS, 1965). Of the movements tested, the only ones reported here are shoulder flexion, extension, external rotation and abduction active ROM. For flexion, authors measured ROM averages of 165°, compared to 158° reported by the AAOS; for extension, authors found 57.3° (53° from the AAOS). For external rotation, measurements were on average 99.6° (AAOS: 90°) and finally, in abduction, authors measured 182.7°, compared to 170° for the AAOS. In a subsequent study, Walker et al. (1984) measured shoulder joint ROM with a large 360-degree goniometer calibrated in 1-degree increments with 32 cm arms. Two investigators were needed to evaluate the ROM, one for taking the measure and one to read it. Researchers collected five different ROM measures: shoulder abduction, flexion, extension and medial / lateral rotation. The result of this investigation was a single database for shoulder ROM whereby women had larger ROM compared to men for most movements (see later in this section) (Walker et al., 1984). Later on, Greene and Wolf (1989) wanted to establish a comparison between two measurements devices: the Ortho Ranger (an electronic computerized goniometer made by Orthotronics Inc., Florida) and a standard protractor goniometer. The dominant upper extremity was measured for the following shoulder movements: flexion, extension, abduction, adduction and internal / external rotation, as well as for movements of other joints (elbow and wrist). For all movements, the estimated standard deviations of measures taken with the Ortho Ranger were larger than those of the goniometer. Both instruments demonstrated high inter-trial reliability, although values taken with the goniometer were slightly higher for all movements.

Since intrarater reliability of goniometric measurements had been found to be greater than interrater reliability, in Sabari et al.'s study (1998), only one examiner took goniometric measurements of shoulder flexion and abduction, with two trials in each of passive and active ROM, in a seated position. Results showed range of motion of 160.20° in the passive and 157.67° in the active shoulder flexion and 158.10° in the passive and 156.17° for the active abduction motion. Moreover, results generally indicated larger values reached in passive range of motion trials than the active ones. In the Boon and Smith (2000) study, authors used standard plastic long-armed (12-in) goniometers with 1° increments to establish reference values for full range of shoulder external and internal rotation motion, in a supine lying down position. Two types of recordings were made; one with the scapula stabilized and one without, which showed larger ROM values in the non-stabilized condition (Boon and Smith, 2000). Barnes et al. (2001) measured shoulder ROM in 40 subjects (20 males, 20 females ranged from 4 to 70 years). Bilateral active and passive forward elevation, abduction, internal and external rotation at 90° of abduction, external rotation with the arm adducted, and extension were measured once in all subjects. Within each age group, half of the subjects had active motion measured first and the other had passive motion measured first to minimize the effects of warm-up on subsequent shoulder ROM. All measurements were made with a 360° clinical goniometer with 10-inch movable arms with standard techniques. Age was found to have a statistically significant effect on all motions analyzed, and female subjects had statistically greater ROM than male subjects for all motions measured. Also, authors reached contrasting conclusions with the relationship between ROM data and shoulder dominance. The dominant shoulder showed greater motion for external rotation contrary to the internal rotation and extension that were larger for the non-dominant shoulder ($p < .01$ for all relations; see later in this section) (Barnes et al., 2001). However, authors could not interpret their findings to reflect systematic bilateral differences in shoulder ROM data and noted that the magnitude of difference between shoulders was relatively small and thus may be difficult to detect clinically.

Later, Awan et al. (2002) used commercially available digital inclinometers with 1° increments for all measurements. They used this instrument to determine significant differences between passive shoulder internal / external rotation by using three different methods: scapula stabilized or not, and the visual inspection method; as such, for the external rotation (ER) – visual measurement, the end range of motion was determined as the point at which the posterolateral acromion was visualized to rise off the table. Ninety-three percent of the 56 unimpaired individuals (30/32 men, 22/24 women) participating in this study were right-handed. The subject average ROM for the external rotation was 116.9° for the right arm and 113.3° for the left one. The ANOVA did not reveal any significant interaction between arm dominance and measurement technique. Intrarater reliability was found to be moderate for ER (0.58-0.67) and equally good for all measures of internal rotation (IR) (0.63-0.71) and interrater reliability was low to moderate for ER (0.41-0.51) and all measures of IR (0.41-0.66). More recently, in a book chapter accepted for publication by our group (Lomond et al., 2009), authors measured shoulder active ROM for flexion and extension movements with the Simulator II (BTE technologies™). Their sample was composed of 16 participants with neck / shoulder pain (pain intensity ≥ 3/10 for at least 3 months within the past year). They assessed ROMs with one administrator and on two different sessions with 48 hours apart. The subjects were seated while they were executing the different motions and their trunk and upper torso was strapped to avoid movement compensations. Although focusing on a different clinical population, these results are informative in that they present the only study published in the scientific literature reporting shoulder ROM measurements made with the Simulator II system. Findings from this pathological group are reported below, along with results from all studies mentioned above.

Table 2 – Summary of shoulder ROM reference data taken from the literature. Values are means ± SD, expressed in °

Study	ROM type / Instrument	Flexion	Extension	External Rotation	Abduction
The American Academy of Orthopaedic Surgeons (1965)	Active ROM - Goniometer	158	53	90	170

Boone & Azen (1979)	Active ROM - Goniometer	165 ± 5	57.3 ± 8.1	99.6 ± 7.6	182.7 ± 9.0
Walker et al. (1984)	Active ROM - Goniometer	169 ± 9	49 ± 13	X	175 ± 16
Greene and Wolf (1989)	Active ROM - Goniometer	155.8 ± 1.41	155.8 ± 1.1	83.6 ± 2.96	167.6 ± 1.81
	Active ROM - Ortho Ranger	149.1 ± 3.13	149.3 ± 2.24	80.3 ± 3.81	158.0 ± 3.67
Sabari et al. (1998)	Goniometer - Passive ROM average	160.20 ± 15.14	X	X	158.10 ± 16.15
	Goniometer - Active ROM average	157.67 ± 14.84	X	X	156.17 ± 17.02
Boon and Smith (2000)	Goniometer - Passive ROM	X	X	108.1 ± 14.4	X
Barnes et al. (2001)	Goniometer - Passive ROM	X	D: 83.2 ± 11.2 ND: 84.6 ± 11.3	X	D: 194.6 ± 16.5 ND: 195.0 ± 16.6
	Goniometer - Active ROM	X	D: 67.3 ±8.7 ND: 68.7 ± 9.3	X	D: 187.6 ± 16.1 ND: 188.6 ± 15.4
Awan et al. (2002)	Goniometer - Passive ROM	X	X	Right: 113.3 ± 9.6 Left: 116.9 ± 8.8	X
Lomond et al. (2009)	Simulator II - Active ROM Test (Day1)	173.2 ± 38.7	X	X	143.5 ± 50.2
	Retest (Day2)	184.8 ± 36.1	X	X	165.4 ± 38.2

D: Dominant arm
ND: Non-Dominant arm

Moreover, other studies have been recently investigated the shoulder joint but with more modern equipments than goniometers. Meeteren et al. (2002) studied test-retest reliability of shoulder muscle strength with the Biodex® dynamometer (Multi-joint system 2). They tested strength in abduction / adduction and external / internal rotation directions on a gender-balanced sample of 20 subjects. All measurements were done in a sitting position with subjects strapped to the chair (upper trunk, pelvis and contralateral leg), with a footrest and a gravity correction.

Every session was done with a random movement order, a warming-up session and a rest period of 60 seconds between angular velocities; the test-retest was done on a 2-week interval. On their sides, Orri and Darden (2008) observed the reliability and validity of the « iSAM 9000 Isokinetic Dynamometer ». This equipment is described as a free-standing dynamometer that tests the muscular strength using a concentric isokinetic mode of operation. The study established the mechanical validity and reliability of the iSAM9000 by comparing the iSAM9000 values and the Cybex6000 ones. The study was done on 40 men and 20 women adult volunteers, healthy, free of musculoskeletal, cardiovascular and neuromuscular conditions. Before testing, both dynamometers were calibrated and they did not use a gravity correction. Subjects were strapped to stabilize the hips, upper body and legs, plus, they had at least three warm-up sessions. For the testing, they had 15 s of rest after the warming-up sessions and had to push and pull as hard as they could for the 5 maximal test repetitions. The following muscles were tested: trunk, right and left knee, left and right shoulder. They had to come back for a second test session within 3 to 5 days. However, unfortunately, we cannot compare both of those studies with the ones previously cited because they are not testing the same shoulder proprieties. These two studies were looking at torques values and not range of motion ones.

To summarize, the literature indicates that most of the research on shoulder ROM has assessed the same four movements as those that we chose to assess in the present study. However, in theory, the system used in the present study allows for range of motion measurements since electropotentiometers are built into the system, and they are not dependent on manual positioning from the experimenter. Also, past research has focused on intrarater reliability while using clinical tools, and on ROM measures taken in either supine or seated positions. Moreover, researchers have assessed two different means to achieve ROM, passive (i.e. where the limb is moved by the administrator) and active (i.e. where the limb is moved by subject muscle actions). Results have generally demonstrated that passive ROM was always higher than active ROM. However active trials seem to have been chosen in most studies because it is a more functional measure of what individuals can actually achieve by themselves. Finally, two other important factors have been identified by the literature on ROM: differences between males and females, and effects of hand dominance, or handedness. These two factors will be addressed in more details in subsequent sections.

2.3 Handedness relationship with ROM

Handedness (also referred to as laterality, or hand dominance) is an attribute of human beings defined by their unequal distribution of fine motor skills between the left and right hands. An individual who is more dexterous with the right hand is called right-handed, and one who is more skilled with the left is said to be left-handed. A minority of people is equally skilled with both hands, and is termed ambidextrous. Similarly, manual asymmetry is characterized by the tendency to favor one hand for performance of skilled unimanual tasks (Sainburg and Kalakanis, 2000; Bagesteiro and Sainburg, 2002). According to statistics from the late 1990s, there was at the time a lower incidence of left-handedness in the general population, with studies suggesting that approximately 7 to 10 percent of the adult population may be functionally left-handed, and that left-handedness is more common in males than females (Raymond et al., 1996).

One of the tests designed to assess a person’s handedness is the Edinburgh Handedness Questionnaire (Oldfield, 1971). At the completion of the questionnaire, a laterality score can be obtained, which is also called a Geschwind score (GS). A score of -100 means that the subject responded “always left” on all items, and a score of +100 indicates “always right” on all questions (Knecht et al., 2000). This is a preference-based measure and shows a J-shaped distribution of handedness in the general population (Knecht et al., 2000). The Edinburgh Inventory is known from past studies to detain good test-retest reliability thus, favoring its comparability with data from the literature (Ransil and Schachter, 1994).

Earlier studies on ROM measurement reported left-right differences with disregard to subjects' handedness. First, Cobe (1928) reported in his study that the left wrist had greater ROM than the right one in every motion in men, except for the ulnar flexion in the supine position. However, results from the women population differed, with only radial flexion in supination and dorsiflexion in pronation being slightly larger in amplitude on the left than on the right. Authors questioned this possible difference across sexes because of small and uneven sample sizes (100 men and 15 women). Moreover, the significance of these results was not confirmed by statistics and the measurement method was not very accurate (measures were taken with two protractors, one for each hand, with subjects leaning on a flat surface (table)). In fact, the authors at the time acknowledged that differences obtained were most likely not clinically meaningful and could not explain otherwise their findings of left-right differences. Later, Allander et al. (1974) used a goniometer to collect the same variables as those reported by Cobe and found smaller ROMs on the right side than the left ($p < 0.001$) for the wrist and, in some age groups, for the shoulder. To interpret these findings, authors hypothesized that the original skeletal structure probably plays some role in this difference between right and left side. Indeed, the radio-ulnar width in 434 males aged 16 to 27 years was greater on the right side ($p < 0.001$), and bone density in the lower end of the radius, as measured by Ekman and co-workers (1970), was also greater on the right side. In light of these previous measurements, authors believed at that time that there may be some biological differences in earlier years of life, and that these may produce differences in joint function in later years (Allander et al, 1974). However, no such effect of side was found for shoulder measurements.

Later, Boone and Azen (1979), the first ones to report handedness in their analyses of ROM, found that, in a right-handed sample of male subjects, ROM differences between the left (non-dominant) and right (dominant) joints were not constant across movements; for example, in the age range of 6 to 12 year olds, for the shoulder joint, they found greater ROM on the right compared to the left for the horizontal flexion movement ($p < 0.001$). However, they found larger ROM on the left than the right ($p < 0.01$) for the backward extension and inward rotation task in the age range of 20 to 29 years old, ($p < 0.005$). Nevertheless, they concluded that since no consistent pattern was noted, their data could be associated to chance; thus, right and left amplitudes were averaged for following analyses. In a subsequent study, Smith and Walker (1983) found only one significant left-right difference in their right-handed sample, with passive elbow flexion in females aged 55 to 64 years showing a significant difference of 4° between right and left sides. Despite this finding for the elbow joint, the absence of significant side difference in other joints and movements lead authors to conclude to an overall non-relationship between range of motion and handedness. In contrast, Günal et al. (1996) found in their study of 1000 male right-handed subjects that ranges of motion on the right side were significantly smaller than those on the left (non-dominant side). Authors attributed the smaller amplitude of motion on the right side to slight degenerative changes in these more frequently used joints as well as damage to the ligaments of the right upper extremity in a right-handed population (Günal et al., 1996). Later on, Barnes et al. (2001) assessed a sample of 40 subjects (20 males, 20 females) and found that the non-dominant shoulder had greater active internal rotation ($p < .01$), passive internal rotation ($p < .01$), active extension ($p < .01$), and passive extension ($p = .013$) than the dominant shoulder. However, the dominant shoulder displayed significantly greater active and passive external rotation than the non-dominant shoulder, regardless of whether the arm was abducted or adducted at the time of measurement ($p < .01$ in all cases). Moreover, no significant differences were found between the two shoulder sides for forward elevation or abduction ROMs. On the other hand, authors noted that the magnitude of difference between shoulders for extension was relatively small and thus may be difficult to detect clinically. Authors also performed a follow-up study specifically on the 4-10 years old group and no significant differences were found between dominant and non-dominant sides for forward elevation or abduction, and the effects of shoulder dominance on external rotation with the arm adducted and extension were not statistically significant (Barnes et al., 2001).

In conclusion, taken together, these data point to the absence of consensus on bilateral differences and handedness effects on shoulder joint ROM. Factors such as variations in population sample and composition, study design, and testing methods undoubtedly contribute to this absence of consensus (Barnes et al., 2001). As such, the way in which handedness was assessed is rarely reported in the literature. Moreover, the degree of hand dominance (i.e. how much a person favors their dominant hand) has never been taken into account in studies on upper limb ROM.

2.4 ROM and Sex

In previous comparisons of physical performance across sexes, men and women seemed to differ with respect to nearly all variables. For instance, physical strength and power have been shown to be generally greater in men than women (Fulco et al., 1999). Shoulder strength has been shown to be higher in men, whether isokinetic (Alderink and Kuck, 1986) or isometric strength (Wilke et al., 1993; Hughes et al., 1999) is considered. In general, this evidence of higher muscle strength has been suggested to be mainly due to the larger body mass and lower percentage of body fat in men (Cagnie et al., 2007), along with other anthropometrical differences such as height, shoulder width and lengths of limbs, which can also affect functional performance (Karlqvist et al., 1998). Other studies have also shown differences between genders, some indicating that women have greater muscular endurance capacity than men (Fulco et al., 1999;

Hunter and Enoka, 2001). In comparison, the data from the literature on the effects of sex on joint ROM are more equivocal. Cobe (1928) obtained results that indicated generally larger ROM in women for wrist movements. The author hypothesized that results could reflect the constant small movements in sewing, knitting, etc., typically performed by women, in contrast to heavier occupations of men (Cobe, 1928). However, the researcher recommended great caution with the interpretation of the data due to the low sample size, to which we can add imprecise methodologies, the absence of statistical analyses and of clinical meaningfulness. Clarke et al. (1975) measured gleno-humeral ROM from healthy subjects and others with frozen shoulder syndrome and obtained higher ROM for women for every movement, including total rotation (146.1° vs 138.4°), external rotation (56.2° vs 50.1°) and abduction (81.1° vs 77.4°). Smith and Walker (1983) also showed an amplitude advantage for the female subjects; for both active and passive elbow flexion, females had more amplitude than males (differences ranging from 4° to 6°). A year later, Walker et al. (1984) generated a database for shoulder ROM in which women had larger ROM compared to men for most movements, measured by a goniometer. In it, women had higher ROM by 20° in abduction, 9° for flexion, 11° for extension, 7° for medial rotation and 9° for lateral rotation. In the Barnes et al. (2001) study, female subjects had statistically greater ROM than male subjects for all motions measured; this was true for both active and passive modes. Their data regarding sex and shoulder ROM confirmed the overall clinical impression that female subjects have a greater magnitude of motion than male subjects. The motions with the largest differences were abduction, internal rotation and external rotation with the arm adducted (Barnes et al., 2001). To summarize, there seems to be a general agreement between the studies to confirm that women generally display more range of motion than men. This information could have some practical implications, for example, towards recommending the use of gender-specific reference values in the clinical setting. Unfortunately, very few normative datasets are currently established to provide sex-specific reference values for shoulder function; thus, specific gender datasets could be an important asset in the clinical setting.

2.5 Why study women exclusively?

With regards to MSDs, both incidence and prevalence of musculoskeletal disorders have been reported to be higher in women than in men (Hagberg and Wegman, 1987; Kilbom, 1988; de Zwart et al., 1997; Leijon et al., 1998; Persson et al., 2001; Kishi et al., 2002;). Also, some studies revealed that women typically report higher morbidity rates in the upper body than do men (Chiang et al., 1993; Bernard et al., 1994; Bergqvist et al., 1995; Skov et al., 1996; de Zwart et al., 1997; Nordander et al., 1999). Recently, Kilbom and Messing (1998) expressed possible reasons to explain the higher musculoskeletal morbidity rate among female workers. The first reason related to this phenomenon is biological differences between sexes: body size, muscular capacity, aerobic capacity, and hormonal conditions are thought to play roles in making women more susceptible to the onset of musculoskeletal disorders. Another related factor could be that some tools used at the workstations and the workplace itself may not be properly adjusted to the anthropometric characteristics of women (Morse and Hinds, 1993; de Zwart et al., 1997). Related to this, relative physiological workload for women are likely to be higher compared with men exposed to similar work demands, thereby rising the risk of an acute or chronic musculoskeletal overload (Suurnäkki et al., 1991). Moreover, some researchers reported women to be more often assigned to highly repetitive movements, static postures, and monotonous tasks than are men (Mergler et al., 1987; Lundberg et al., 1994; Messing et al., 1994; Fransson-Hall et al., 1995; Messing et al., 1998) for example within the manufacturing industry (Cox and Cox, 1984), which shows a high prevalence rate of neck and shoulder MSD especially among women.

Differences in the expression of psychosocial factors such as stress and interpersonal relations may also play parts in the differences in reporting MSDs between men and women (Kishi et al., 2002). Also, outside of work, females may be more often exposed to risk factors for MSDs during household and child care activities than are men (Chiang et al., 1993; Lundberg et al., 1994; Kilbom and Messing 1998). In addition, gender-related differences may be related to information bias, as women may be more likely to express or report health problems. There have also been reports of significant gender differences in perceived job control which is thought to be higher in men (Roxburgh, 1996); also, women are more vulnerable to job stress, as women are more adversely affected by high job demands, and high job routinization (Kishi et al., 2002).

In summary, the literature suggests that there are differences in upper limb function and accordingly, possible UEMSD risk factors between males and females. Unfortunately, most of the research on work-related upper limb characteristics has considered both sexes together without the possibility to address differences in injury mechanisms between sexes. Since there is a higher prevalence of UEMSD among women, more studies are needed to characterize upper limb function of this particular group of subjects.

2.6 Simulator II background

As the literature has shown, most epidemiological investigations into shoulder disorders suffer from methodological limitations, in particular concerning exposure assessment (Crawford and Laiou, 2007). Simulated work testing, such as what is typically done using the Simulator II, is used by rehabilitation specialists for the treatment of individuals with upper extremity (UE) dysfunction, to evaluate an individual's functional ability to perform and to assess their potential for progress toward a return to normal function (Anderson et al., 1990; Lee and Hui-Chan, 2001; Ting et al., 2001). Moreover, established biomechanical reference values can be used by the occupational therapist in determining and evaluating the degree of disability of a patient compared to the general population, monitoring the progress of work hardening programs and providing goals for which to strive during the rehabilitation process (Anderson et al., 1990; Kennedy and Bhambhani, 1991; Lee and Hui-Chan, 2001). These evaluations can help to prevent a potentially productive person from losing his working life prematurely and may protect the workers' compensation system from considerable abuse (Ting et al., 2001).

Many rehabilitation programs have used the BTE simulator II (Simulator II) for both testing and treatment purposes (Bettencourt et al., 1986). The Simulator II has been designed to reproduce specific movements against measurable resistances over a measurable period of time (Lee et al., 2001). Its different attachments, that can be interchangeably fixed to the exercise head (the main component of the system), allow the reproduction of a variety of physical tasks for evaluation and treatment, ranging from dexterous motion such as finger pinch to dynamic motion of large amplitude such as pulling and pushing (Lee et al., 2001). The system is equipped with rotary potentiometers and strain gauge load cells to allow the recording of forces applied on the attachments and displacements of the exercise head. The system can perform in either the static or dynamic mode. The static mode locks the exercise head in a chosen position for isometric exertions and recording the maximum force output. On the other hand, the dynamic mode allows the clinician to define a chosen resistance at the exercise head while the patient performs a specific motion or repeated movements and records cumulative power output over a given time period (Lomond et al., 2009). The principal characteristics of this instrument include:

- Quantitative measurements and documentation of the client's output;
- Simulation of movements with resistance in one or two directions;
- Simulation of a broad range of tasks in a small amount of space;
- Assessment of strength and function in the performance of static and dynamic tasks.

The Simulator II appears to be the most thoroughly researched instrument for work simulations, with concurrent validity investigated in healthy and injured populations (Innes and Straker, 1999), however only for a limited number of the Simulator II's 22 attachments (Trossman et al., 1990; Coleman et al., 1996). In their study, Kennedy and Bhambhani (1991) compared oxygen uptake (VO_2) and heart rate (HR) during simulated and real upper extremity manual materiel handling (MMH) tasks at three work intensities in healthy men and found strong correlations between both (r for VO_2= 0.74-0.87 and r for HR = 0.59-0.78, respectively). In the same way, Ting and colleagues (2001) found significantly lower VO_2 and HR values during a simulated lifting task performed by healthy males than in an actual lifting task. In addition, several authors compared the Simulator II #162 (grip strength) tool to the Jamar © dynamometer with positive result; in a retrospective chart review, a correlation between Jamar and Simulator II grip strength test measures was demonstrated for non-injured and injured arms respectively (r = 0.625 and 0.93) (Beaton et al., 1995).

Until now, good reliability of the Simulator II has been demonstrated by some researchers for tasks performed in the static mode (Anderson et al., 1990: r = 0.91-0.98 for static grip strength; Trossman et al., 1990: ICC = 0.98 for wrist flexion strength). On the other hand, the reliability of measurements taken from tasks performed in the dynamic mode has yielded more variable results. Moreover, various studies have planned protocols applying constant force to the Simulator II's attachment in the dynamic mode and noted large variability in measurements, adding doubts about the validity of the equipment in the dynamic mode (Fess, 1993; Cetinok et al., 1995; Coleman et al., 1996; Ting et al., 2001).

To summarize, the Simulator II provides objective data (force, distance, ROM and power) during simulated work and it affords the clients clear feedback, which can help to motivate them (Kennedy and Bhambhani, 1991). The variety of available attachments for this machine allows combinations of movements that can theoretically replicate all physiologic motions of the UE. However, no studies have investigated the properties of the Simulator II in measuring shoulder ROM. This system can be potentially used to make such measurements of ROM, there is a need to assess how reliably such joint ROM assessments can be made using the Simulator II.

2.7 Reliability

Reliability can be defined as the extent to which a test or a measure is consistent and free from error (Portney and Watkins, 1993). It is typically reported using a coefficient, based on the variance, or the measure of differences among scores in a sample. Reliability also depends on the consistency of measurement results and thus, to a relative absence of measurement errors. In addition, to reflect good reliability, the test score should be dependable across evaluators, subjects and the date or time of test administration (Reesink et al., 2007). In order to achieve high reliability in assessing clinical instruments, it is important to have standardized testing protocols for reproducibility in a clinical setting (Leggin et al., 1996).

Reliability is especially important in the clinical setting. An adequate clinical instrument requires evidence of clinical practicality, reliability, and validity (Fess, 1986; Bear-Lehman and Abreu, 1989; Fess, 1990). Whether we are talking about confidence in the instrument, or in the testing procedure, reliability of a measurement tool is crucial to clinicians when assessing clients, monitoring the efficacy of treatment and planning interventions (Innes and Straker, 1999). Reliability can also be used to explore factors that contribute to inconsistent performance of subjects who are being evaluated (Lee and Hui-Chan, 2001). This is especially important, since performance inconsistency may also be generally attributed to inaccuracies in the instrument, confounding variables specific to the construct being measured and errors associated with taking the measurements

(Lee and Hui-Chan, 2001). Additionally, the reliability of some measures can be compromised by unclear instructions: for example, walking ‘as quickly and as far as possible’ (Heinrich et al., 1985) might lead some patients to opt for speed and others for distance. Reliability of tests that are currently used as performance measures has not always been rigorously examined (Harding et al., 1994). Thus clinicians need to be provided with more information or confirmation about their equipment so as to optimize their use (Bhambhani et al., 1993).

Reliability over two sessions, i.e. test-retest reliability, is necessary in areas where long-term follow-up is important (Gajdosik and Bohannon, 1987). When test-retest reliability is good, unilateral comparison over a period of time is possible (Meeteren et al., 2002). The test-retest reliability determines the consistency of measures or scores from one testing occasion to another. It assumes that the characteristic being measured does not change over the time period and measures the degree to which measurement is stable, so that an accurate assessment of the consistency of the subjects’ performance can be obtained (Anderson et al., 2006). This type of reliability has been the most commonly investigated one in work-related assessment. This demonstrates the importance placed on ensuring that any change found in assessment is the result of change in the individual and not the result of measurement inconsistencies over time. Test-retest reliability of objective variables can be most influenced by time-dependent effects (i.e. practice, fatigue). In particular, test-retest intervals must be far enough apart to avoid fatigue or learning effects, and close enough to avoid genuine changes in performance (Innes and Straker, 1999). Practically, reliability is typically assessed using correlation coefficients (Pearson, Spearman) as well as intra-class correlation coefficients (ICCs). The ICC is considered preferable to correlation coefficients as a reliability index as it provides a single value for variance estimates that reflect errors within the measurement and true differences in the data set (Portney and Watkins, 2000).

Several studies of reliability of shoulder ROM have been reported in the literature (Table 3). In the Walker et al. (1984) study, 4 subjects were tested with a goniometer to assess shoulder ROM reliability; Pearson correlation coefficients (r) for intratester reliability were high (0.78-0.99): the lower value corresponding to shoulder external rotation movements. The mean error between repeated measurements for subject's motions was 5 degrees (±1°). Conversely, in the Greene and Wolf (1989) study, which was collecting ROM data with 2 different tools (Ortho Ranger and Goniometer), the Pearson correlation was excellent for external rotation (0.92), but moderate for all the other movements (shoulder flexion, extension, abduction, adduction and internal rotation, range from 0.54 to 0.59). Moreover, the intraclass correlation (ICC) for repeated measures with each instrument was good to excellent (0.87 to 0.97) for all movements. In the Sabari et al. (1998) study, ICCs were calculated to assess the reliability of shoulder flexion and abduction ROM between trials 1 and 2 in the same position (seated) using a goniometer as the measurement instrument. Results indicated excellent reliability with ICCs ranging from 0.95 to 0.97, regardless of whether measurements were active or passive. Boon and Smith (2000) determined that inter- and intrarater reliability were poor (0.13 to 0.23) for shoulder internal rotation and moderate to good (0.58 to 0.84) for shoulder external rotation; measured using a goniometer, whether trials where with the scapula stabilized or not. In addition, authors were the firsts to report the Standard Error of Measurements (SEM) for these movements, as assessed by goniometer, which estimates the error associated with each outcome and which serves to indicate the range of scores that can be expected from test to test of the same individual (Portney and Watkins, 2000), which was 9.14 degrees for external rotation recordings. In the Awan et al. study (2002) authors used a digital inclinometer to measure shoulder ROM on both arms (non-stabilized shoulder (NSS) and stabilized only for the internal rotation (SS)). For external rotation, intrarater reliability scores were moderate (0.58-0.67) and poor to moderate for interrater reliability scores (0.41-0.51). Finally, in a book chapter presented by our group

(Lomond et al., 2009), the between-session test-retest reliability of shoulder ROM measurements taken with the Simulator II on 15 subjects with neck-shoulder pain was excellent for the ROM measures tested (flexion and abduction). Correlation coefficients (r) of shoulder functional measures between testing sessions were significant and excellent ($p < 0.05$), as were ICC scores (0.92-0.94). SEMs were also reported from this research to be 1.4 degrees for flexion and abduction measurements, demonstrating a clear advantage of measurement from the Simulator II over the standard goniometer as reported in the Boon and Smith study (2000). Finally, the Minimal Detectable Change (MDC_{90}), which reflects the minimum amount of change in a measurement that is not likely to be due to chance variation in the measurement, was also reported and shown to be 3.3 degrees for flexion and abduction recordings.

Table 3 – Summary of the correlation, from shoulder ROM reference data, healthy subjects

Study	Statistical tests	Flexion	Extension	External Rotation	Abduction
Walker et al. (1984)	Intratester reliability	Above 0.81	Above 0.81	0.78	Above 0.81
Greene et al. (1989)	Intraclass correlation Coefficient - Goniometer	0.96	0.98	0.91	0.96
	Intraclass correlation Coefficient - Ortho Ranger	0.94	0.97	0.87	0.94
	Pearson correlation	0.59	0.57	0.92	0.54
Sabari et al. (1998)	ICC – Passive ROM	0.9503	X	X	0.954
	ICC – Active ROM	0.9714	X	X	0.971
Boon and Smith (2000)	ICC	X	X	Intra: 0.58 Inter: 0.78	X
	SEM	X	X	Intra: 9.14 Inter: 6.61	X
Awan et al. (2002)	ICC	X	X	Intra: 0.67 (left) 0.58 (right) Inter: 0.51 (left) 0.41 (right)	X
Lomond et al. (2009)	Spearman r	0.79	X	X	0.73
	ICC	0.94	X	X	0.92
	SEM	1.4	X	X	1.4
	MDC_{90}	3.3	X	X	3.3

Regarding the other equipments (Biodex and Cybex), studies showed that they had relatively good reliability. Meeteren et al. (2002) had ICC ranged from 0.69 to 0.92 thus, a good to excellent reliability. In the Orri and Darden (2008) one, they had also very high correlation with ICCs from 0.94 to 0.98 for the iSAM9000 for reliability between set 1 and 2 and, they had a very high correlation for the variance between the iSAM9000 and the Cybex 6000 (set 1: r = 0.84-0.93; set 2: r = 0.87-.093). However, none of these studies reported reliability of range of motion measurements.

2.8 Summary

Since we know that musculoskeletal disorders affect a large group of workers, it is important to take these disorders in closer consideration, especially the shoulders disorders while they appear to be a growing problem. Moreover, because neck-shoulder MSDs are more prevalent among women, there is a need for more studies focusing on physical evaluation of this population. In addition, there is a lack of consensus as to whether there are differences in joint ROM between dominant and nondominant sides and on whether these are related to handedness. Since in the clinical setting, the contralateral arm is often used as the reference for measurements taken from the impaired limb, oftentimes with disregard to handedness, it seems important to settle this question as well as to assess the potential importance of the degree of handedness on shoulder ROM measures, which has never been addressed before. The Simulator II provides useful objective data on upper limb function and it affords the clients clear feedback, which can help to motivate them. However, there is a need for more information or confirmation about this equipment, especially relating its psychometric properties to clinically meaningful information. The current belief in the literature is that more reliable, and clinically useful measures of shoulder ROM are needed, which was the motivation behind this study.

CHAPTER 3 – OBJECTIVES AND HYPOTHESES

3.1 Objectives

The general purpose of this thesis was to present reference values for active shoulder range of motion (ROM), measured with the Baltimore Therapeutic Equipment© Work Simulator II (Simulator II), in a healthy female group, to study the association between shoulder ROM with age and anthropometric characteristics, and to analyze the reliability properties of the Simulator II in measuring shoulder ROM.

The specific objectives were:

1. To compare active shoulder ROM values obtained using the Simulator II from those of the literature;
2. To assess the relationships between age and anthropometric (height, weight, segment lengths) data with shoulder ROM;
3. To evaluate the effect of handedness on bilateral shoulder ROM;
4. To evaluate the test-retest reliability properties of the shoulder ROM values measured with the Simulator II;
5. To assess the clinical meaning of the shoulder ROM values measured with the Simulator II using:
    a. Standard error of the measurement (SEM)
    b. Minimal detectable change for the 90^{th} percentile confidence interval (MDC_{90th}).

3.2 Hypotheses

The working hypotheses for this research were the following:

1. Reference data from all ROM will be similar to those found in the literature using different systems, methods and / or healthy groups;
2. There will be strong correlations between shoulder ROM with age and anthropometric characteristics;
3. There will be strong relationships between hand dominance and bilateral shoulder ROM difference values;
4. Test-retest reliability properties of the shoulder ROM values recorded using the Simulator II will be good to excellent (ICC = 0.80-0.95) (Portney & Watkins, 2000).
    a. Correlation coefficient measures between sessions will be significant ($p < 0.05$);
5. The SEM and MDC_{90} measures will be substantially smaller than the peak shoulder ROM values recorded.

3.3 Limitations

While the purpose of the project was to evaluate active ranges of motion at the shoulder, it is possible that other joints and muscles contributed to achieving larger ranges of movement. However we took great care to isolate the arm from the rest of the body by having subjects seated on a chair that was fixed to the floor, with the trunk strapped to the chair and the arm strapped to the attachments. Thus, the shoulder was not entirely isolated and it is possible that some compensatory movements could have occurred. In addition, all subjects were positioned according to the same guidelines and positions were kept constant for each subject from one testing session to the next, however slight differences in positioning may have occurred between subjects and sessions. Moreover, subjects received the same instructions about how to execute the different tasks; however the interpretation of the instructions and the subjectivity of some of them (e.g. as far as possible) as well as subject motivation might have contributed to a certain degree of variability in measurements from one subject to the next.

3.4 Delimitations

Our study sample consisted of healthy right-handed female aged between 20 and 52. Therefore, our conclusions should only be generalized to this specific population. This project only tested active range of motion on the shoulder. For that reason, results cannot be generalized to other shoulder biomechanical measurements such as passive range of motion or strength. Moreover, the custom handmade attachment used for some of the tasks slightly differed from the attachment #802 (the most similar Simulator II standard attachment), thus our results should be interpreted within the context of this particular experimental condition.

CHAPTER 4 – METHODS

4.1 Subjects and study design

A group of 30 healthy female volunteers aged between 20-52 years (mean age ± SD = 28.8 ± 9.3 years) was recruited from the general community to participate in this study. The inclusion criteria to be part of the study were to be healthy, female, right handed, not receive particular training with the upper limb (i.e. not more than 3 times a week of physical training targeting the upper limbs). To be considered healthy, subjects could not report or have reported any musculoskeletal disorder and / or clinical evidence of pathology at the shoulder-neck in the last year and could not score more than 3/10 on a visual analog scale (VAS, where 0 = no pain and 10 = worst imaginable pain) for shoulder pain on testing day. Also, subjects were asked to avoid beginning any new exercise or treatment program in the days prior to, or during their participation in the study. At the initial time of testing, all patients had to maintain their usual routine of daily activities. Each subject signed a consent form (Appendix B) approved by the Research Ethics Board of the Center for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal, at the beginning of the first session. Subjects performed the experimental procedure a first time, and then came back a second time, two days later, at approximately the same time of the day. The biomechanical assessment took place at the Research Center of the Jewish Rehabilitation Hospital (JRH) in Laval.

4.2 Testing apparatus

In order to measure shoulder flexion, extension, external rotation and abduction range of motion (ROM), we used the Simulator II, first marketed in 1979 by BTE technologies™, Baltimore, USA. The Simulator II (Fig. 1 and Fig. 2) was designed to provide and replicate specific upper limb motions to be performed against measurable resistance, over a measurable period of time. This tool was also created to treat upper extremity limb function in a rehabilitation context. The system consists of a software-based controller interface and an exercise head that is electrically activated to be moved up or down and rotated in order to obtain the desired head position. The Simulator II comes with a total of 22 interchangeable attachments for testing. In this study, we used the attachment number 802 (total length = 72 cm, variable lever arm according to the subject's arm length) (Fig. 3) for the external rotation task, and a modified version of this attachment (length = 58.5 cm, lever arm = 41.5 cm) for the other tasks of the study. The modified attachment consists of a rigid metal bar, secured against the subject's arm with Velcro straps, with a square plate at one extremity on which subjects pushed upward with their forearm (Fig. 4).

Figure 1 - Simulator II (front view)

Figure 2 – Simulator II (side view)

Figure 3 – External Rotation attachment

Figure 4 – Flexion, Extension and Abduction attachment

The Simulator II can generally be used in three primary testing modes: static, dynamic and endurance. During trials in each mode, the Simulator II has the possibility to compute a range of functional outcome measures using measurements of force (strain gauge load cell), position (rotary potentiometer) and time. In this study, we used the dynamic mode for the ROM measurements. For each trial, rotation of the exercise head and force data were collected online by the Simulator II software. The following sections will discuss the experimental protocol for each task: flexion ROM, extension ROM, external rotation ROM and abduction ROM. It should be noted that all tasks were performed in a randomized order block, such that both tasks and sides (left, right) were randomly assigned for every subject. In other words, each subject performed all the randomly assigned tasks on the first, randomly designated, shoulder and repeated the same trial sequence with the other shoulder. Below is an example of a randomization sequence (Fig. 5):

Figure 5 - Simulated order of shoulder motion trials

First shoulder: Left ☐ Right ☒

ROM task for shoulder #1 (right shoulder)	Task Order	ROM task for shoulder #2 (left shoulder)	Task Order
Flexion	1	Flexion ROM	1
Abduction	2	Abduction ROM	2
Extension	3	Extension ROM	3
External Rotation	4	External Rotation ROM	4

The random movement order was created by Matlab, version 6.5.1 (The MathWorks, Inc., Natick, MA, USA) for every subject and the selected randomized sequence was replicated during the second session.

Prior to all movements, the subject’s torso and contralateral shoulder were strapped to the chair to avoid trunk movement, and subjects were asked to cross their feet under the chair in order to avoid movement contribution by their legs

(Figs 6 -7). At the beginning of each block, a practice trial was allowed for every movement tested. Following practice trials, 3 trials were recorded for each task, with 30 seconds between trials, and approximately 2 minutes between tasks (with a minimum resistance of 5 Nm). Prior to all movements, the instructions were as follows: “at the go signal, start moving at a comfortable speed, as far as you can without bending your elbow and come back to the initial position”.

Figure 6 –Initial position on the Simulator II (Flexion, Extension and Abduction movements)

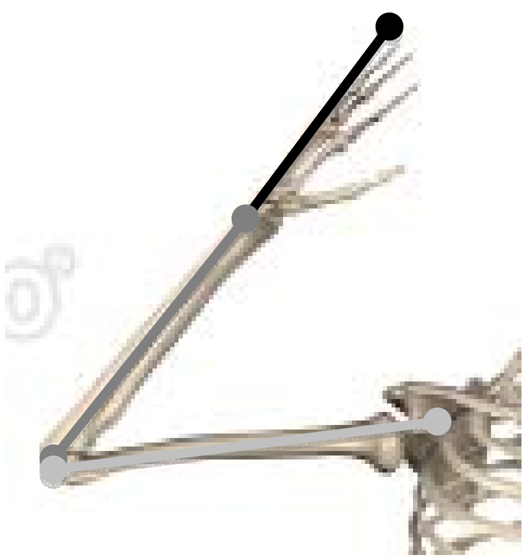
Figure 7 – Initial position on the Simulator II for External rotation movement

4.3 Experimental protocol

Prior to every experimental session, the Simulator II was calibrated following procedures outlined in the instruction manual (BTE technologies™, 2005).

Upon arrival, subjects were asked to sign consent forms. Then, the protocol was explained and all of the participant’s questions were answered. At the beginning of the first testing session, height, weight and lengths of 3 different upper limb segments (upper extremity = shoulder acromion to the olecranon process of the elbow, forearm = olecranon process of the elbow to the head of ulna, hand and finger = head of ulna to the tip of the distal phalange of the middle finger) were measured on each arm and recorded (Fig. 8). To take those measurements, the subject was seated with the back straight and their elbows bent at 90° with their arms and fingers straight ahead. Then, subjects filled out a questionnaire assessing their level of hand dominance (Oldfield, 1971). Following this, subjects were asked to sit on a standard chair (metal frame, padded seat and back rest, without arm rest) and keep a natural static posture. The chair was bolted to a piece of plywood, which was secured to the floor using weights, to insure subject stability. The position of the chair was marked on the floor for the four different movements and kept constant between the two sessions.

Figure 8 – Arm segments (3 segments)



4.4 Flexion, Abduction, Extension and External Rotation ROM recordings

Shoulder joint flexion and extension ROM were assessed with participants seated such that the axis of shoulder flexion-extension rotation, which crosses through the lateral extremity of the head of the humerus at the acromion process of the scapula of the glenohumeral joint, was aligned with the Simulator II's axis of rotation at the center of the exercise head, in the sagittal plane (Figs 9 & 10). The subject's tested arm was secured to the attachment with Velcro strips such that it was aligned with the lateral, longitudinal midline of the humerus in line with the lateral epicondyle. To measure shoulder ROM in abduction, the chair was placed to record movements in the frontal plane (Fig. 11). The axis of shoulder abduction rotation of the glenohumeral joint was assumed to be located at the anterior portion of the acromion process of the scapula, through the center of the head of the humerus of the glenohumeral joint, and was aligned with the Simulator II's axis of rotation at the center of the exercise head. The subject's tested arm was strapped to the attachment such that it was aligned along the posterior, longitudinal midline of the humerus, in line with the olecranon process. For the flexion, extension and abduction tasks, the Simulator II's exercise head was oriented with the shaft facing straight forward (means position #3 for the exercise head) (Fig. 13). For the external rotation ROM trials, we aligned the center of the olecranon process of the elbow joint with the Simulator II's axis of rotation at the center of the exercise head (Fig. 12). The exercise head was oriented at 45° from the horizontal position, with the shaft pointing up at a 45° angle (at position #5 on the exercise head) (Fig. 14), thus the shoulder was in a 45° abduction position. The lever arm of the attachment was measured in accordance with the subject's arm length and was kept constant for the second session. These procedures carefully followed the ones described in the Simulator II user manual for shoulder strength testing in all four directions assessed.

Figure 9 – Flexion ROM initial position

Figure 10 – Extension ROM initial position

Figure 11 – Abduction ROM initial position

Figure 12 – External rotation ROM initial position

Figure 13 – Position 3 of the exercise head

Figure 14 – Position 5 of the exercise head

For the external rotation task, both shoulders were strapped to the chair, and the moving lower arm was strapped by one Velcro strip below the elbow joint and one above the wrist to the attachment. In addition, for the external rotation task, the attachment's length was adjusted such that the subject was able to grab the steal piece that is perpendicular to the attachment, to avoid movement compensation with the forearm. All positioning measurements were noted and kept the same for the second visit.

4.5 Analysis

For each trial, shoulder ROMs (flexion, extension, external rotation and abduction) were measured as the difference between the maximum and starting angular positions of the exercise head, calculated automatically and for each movement by the Simulator II software. For analyses, we retained the peak ROM trial across the three trials, for every movement, for each shoulder of each subject on both sessions.

For each subject, age and anthropometric information (height, weight and arm segment lengths) was gathered and descriptive statistics (mean, standard deviation) were computed for each measure across the entire group. Pearson correlation coefficients were calculated using Statistica (Statsoft, Inc., Tulsa, OK, USA) to determine the relationships between age and anthropometric (height, weight, segment lengths) data with every ROM (flexion, extension, external rotation and abduction) on both shoulders. Pearson correlation coefficients were interpreted based on Landis and Koch (1977) and Bovens et al (1990) references.

To assess left-right differences in ROM, we computed a % difference by calculating the difference in each ROM between measurements on the left and the right sides for each subject, one session at a time. We then divided this difference by each subject's left-right averaged ROM and multiplied by 100 to obtain a % difference for each subject. We then averaged these individual % differences across the entire group. To statistically assess the left-right differences, we computed Pearson correlation coefficients between measurements on each side, as well as paired t-tests to compare left and right side measurements.

Handedness scores were calculated according to the method outlined by the author (Oldfield, 1971). The approach consists of computing the difference between answers to functional questions beginning with “indicate your preferences in the use of hands in the following activities”, with added contexts such as writing, throwing, using a toothbrush, a spoon or a broom, etc. Thus, for every task, participants indicated their preferences in the use of hands by putting a check mark in the appropriate column (right or left hand). Where the preference was so strong that the participant would never try to use the other hand, unless absolutely forced to, participants indicated 2 checks in the same column. If the participant typically used either hand, they put a check in both columns (Table 4). The final handedness score was then computed by adding how many times subjects answered Right and how many times they answered Left, subtracting the right total from the left total to get the difference, dividing the difference by the cumulative total and multiplying by 100. The suggested interpretation of the final score is the following: below -40, the subject is left-handed, between -40 and 40, the subject is ambidextrous and above 40, the subject is right-handed.

Table 4 – Handedness questionnaire interpretation

	Left		Right	
1. Writing				
2. Drawing				
3. Throwing				
4. Scissors				
5. Toothbrush				
6. Knife (without fork)				
7. Spoon				
8. Broom (upper hand)				
9. Striking Match (match)				
10. Opening box (lid)				
TOTAL (count checks in both columns)				

Difference	Cumulative TOTAL	Result (Difference / Cumulative total x 100)

To assess the effect of the strengths of right side dominance on bilateral ROM, Pearson correlation coefficients were computed between the handedness scores and the absolute left-right ROM differences, in percent, for each of the four movements. These statistical analyses were performed using Excel.

To investigate test-retest properties of the ROM measures, we first computed paired t-tests to verify if there were significant differences between the peak ROM values of ROM collected on each day. Then, we computed Intraclass Correlation Coefficients (ICCs) on the same values using a website recognized by the scientific research community (cited in Pearson et al., 2009) (http://sip.medizin.uni-ulm.de/informatog/projekte/Odds/icc.html).

The ICC is the analytical approach of choice to assess test-retest reliability by comparing the variability of repeated ROM values between sessions of the same subject, to the total variation across all values and all subjects. The ICC is considered preferable to correlation coefficients as a reliability index as it provides a single value for variance estimates that reflect errors within the measurement and true differences in the data set (Portney and Watkins, 2000). The interpretation of ICC scores is based on this last reference.

Using the ICC, we computed the Standard error of the measurement (SEM) values, which estimate the error associated with each outcome and which serve to indicate the range of scores that can be expected from test to test of the same individual. Values were calculated using the following equation (Portney and Watkins, 2000):

$$SEM = SD \bullet \sqrt{1 - ICC}$$

where SD represents the mean of the standard deviations of each measure on session one and session two and ICC is the mean intra-class correlation coefficient between session one and session two. SEM was also used to calculate the minimal detectable change for the 90th percentile confidence interval (MDC_{90}), as follows (Stratford, 2004):

$$MDC_{90} = SEM \bullet \sqrt{2} \bullet (z\ score)_{90}$$

where $(z\ score)_{90}$ is the z score associated with the 90th percentile confidence interval (i.e. z = 1.65) and SEM is the previously described standard error of the measurement. MDC_{90} is a measure that reflects the minimum amount of change in a measurement that is not likely to be due to chance variation in the measurement; since the MDC_{90} is highly dependent on the size of the reliability correlation, instruments with poor stability across repeated tests will have sizable MDC_{90} values (Haley and Fragala-Pinkham, 2006). Finally, Pearson correlation coefficients were computed as another score for test-retest measurement properties in order to more easily compare our results with those of the literature.

CHAPTER 5 - RESULTS

5.1 Subject characteristics

5.1.1 Age and anthropometric data

A summary of the age and anthropometric data of the subject sample is presented in the following table.

Table 5 – Age and anthropometric data (average ± SD)

	Average (n=30)
Age	28.80 ± 9.26
Weight (kg)	63.76 ± 15.12
Height (cm)	162.49 ± 11.86
Upper extremity length – Left (cm)	36.52 ± 2.12
Forearm length – Left (cm)	24.52 ± 1.28
Hand and Finger length – Left (cm)	18.20 ± 0.97
Upper extremity length – Right (cm)	36.42 ± 2.10
Forearm length – Right (cm)	24.60 ± 1.21
Hand and Finger length – Right (cm)	18.27 ± 0.92
Handedness questionnaire (%)	77.33 ± 16.80
VAS scale (0-10)	0.17 ± 0.59
Average time between sessions (hours)	47h36 ± 1.89

5.1.2 Questionnaire and VAS scale

The scores on "The Edinburgh inventory" confirmed that all subjects were right-handed. The interpretation of the scores was that if they were below -40, subjects were left-handed, between -40 and 40, subjects were ambidextrous and above 40, were right-handed. The range of scores was from 40 to 100 with an average of 77.33 (± 16.80), indicating clear right hand dominance. Visual-Analog Scale

(VAS) scores for pain are reported here in order to confirm that our subjects were pain-free, in accordance with our participation criteria (subjects had to score below 3 on the 0-10 VAS range before every session).

5.2 ROM Reference data

Table 6 below indicates the group average ± standard deviation values for subjects' peak trials (i.e. each subject's highest of three trials) for shoulder ROM in the four movement directions, recorded on the Simulator II. As shown on the table, the general trends of the dataset are that the highest ROMs were for the movements of flexion and abduction, and the lowest in external rotation ROM. As exposed in the table 6, amplitudes seemed consistent across testing sessions and across sides. Possible explanations are later discussed (see Discussion section).

Table 6 – Shoulder active ROM reference data (values are expressed in °)

	LEFT Shoulder		RIGHT Shoulder	
	Session 1	Session 2	Session 1	Session 2
Flexion	233.10 ± 28.20	231.28 ± 29.82	228.98 ± 38.81	225.70 ± 34.63
Extension	73.57 ± 15.04	74.34 ± 15.32	73.88 ± 17.21	72.78 ± 18.34
External Rotation	48.82 ± 13.29	49.19 ± 9.79	51.07 ± 11.53	48.42 ± 7.16
Abduction	214.18 ± 14.03	213.17 ± 9.50	204.93 ± 13.56	203.49 ± 13.71

Table 7 summarizes maximal ROM reference values found in the scientific literature from studies using similar methodologies. The table reflects that data obtained in this study are slightly different from those of the literature, for all movements.

Data from shoulder flexion and abduction ROM collected in the present study were generally higher than values found in the literature, and conversely, our external rotation ROM data were smaller than the ones found in the literature. Similarities, differences, and potential causes for these differences, are discussed in light of the different methodologies used in the Discussion section.

Table 7 – Comparison of ROM data of the current study with reference data in healthy subjects taken from the literature (values are means, expressed in °).

Movements	Boulay, 2009	Literature review range
Flexion	230	149-184
Extension	74	49-155
External Rotation	49	80-116
Abduction	209	143-195

5.3 Relationships between age, anthropometric data and active shoulder ROM

As can be seen in Table 8 and 9 (left and right shoulders), statistical analyses showed some moderate to good correlations (0.5 to 0.75) between ROMs and age and anthropometric characteristics (identified with *). For the left shoulder (Table 8), there was a negative correlation between session 2 abduction ROM and weight (-0.55). For the right shoulder, as observed in Table 9, there was a correlation between extension ROM measured on the second session and lower arm length (0.56).

We also observed some poor to moderate correlations (0.25 to 0.50, identified in **bold**), for the left shoulder between age and external rotation ROM, between session 2 extension ROM and the upper extremity and forearm lengths, between session 2 external rotation ROM and hand and finger length, and finally between session 1 abduction ROM and height (negative). For the right shoulder, poor to moderate correlations were observed at several places, for instance between forearm segment length and abduction, flexion (session 2) and extension (session 1) ROM, between session 2 abduction ROM with weight and also upper extremity segment length, between session 1 abduction ROM with hand and finger length and between session 2 extension ROM with upper extremity length.

Other moderate to good correlations were observed. Arm segment lengths (3) were correlated with overall height and with each other. There were also poor to moderate correlations between age and height, and between different ROMs. Finally, the test-retest correlations for the same ROM will be addressed later on in this section.

Table 8 – Pearson correlations between age, anthropometric and ROM data – Left shoulder.

	Age	**Weight**	**Height**	**UE**	**FA**	**Hand**	**Flex 1**	**Flex 2**	**Ext 1**	**Ext 2**	**ER 1**	**ER 2**	**Abd 1**	**Abd 2**
Age	1.00	0.16	**-0.31**	0.00	-0.02	-0.08	0.14	-0.06	0.11	-0.13	**0.44**	**0.40**	0.15	-0.03
Weight	0.16	1.00	0.23	0.21	0.05	0.04	-0.15	-0.17	-0.26	-0.19	-0.13	-0.03	-0.29	-0.55*
Height	**-0.31**	0.23	1.00	0.53*	0.51*	**0.44**	-0.07	0.02	0.06	0.23	-0.18	-0.22	**-0.32**	-0.22
UE	0.00	0.21	0.53*	1.00	0.60*	**0.31**	0.02	0.04	0.09	**0.41**	-0.04	-0.21	-0.25	-0.27
FA	-0.02	0.05	0.51*	0.60*	1.00	**0.39**	0.03	0.08	0.24	**0.49**	-0.02	0.10	-0.20	-0.02
Hand	-0.08	0.04	**0.44**	**0.31**	**0.39**	1.00	0.03	0.01	-0.20	-0.04	-0.05	**-0.33**	-0.13	-0.16
Flex 1	0.14	-0.15	-0.07	0.02	0.03	0.03	1.00	0.90*	**0.45**	**0.35**	0.22	-0.02	0.55*	0.27
Flex 2	-0.06	-0.17	0.02	0.04	0.08	0.01	0.90*	1.00	**0.36**	**0.45**	0.16	-0.06	**0.43**	0.26
Ext 1	0.11	-0.26	0.06	0.09	0.24	-0.20	**0.45**	**0.36**	1.00	0.62*	**0.31**	0.19	**0.46**	**0.49**
Ext 2	-0.13	-0.19	0.23	**0.41**	**0.49**	-0.04	**0.35**	**0.45**	0.62*	1.00	0.25	0.10	0.09	0.21
ER 1	**0.44**	-0.13	-0.18	-0.04	-0.02	-0.05	0.22	0.16	**0.31**	0.25	1.00	0.60*	0.14	0.14
ER 2	**0.40**	-0.03	-0.22	-0.21	0.10	-0.33	-0.02	-0.06	0.19	0.10	0.60*	1.00	0.07	0.09
Abd 1	0.15	-0.29	**-0.32**	-0.25	-0.20	-0.13	0.55*	**0.43**	**0.46**	0.09	0.14	0.07	1.00	0.67*
Abd 2	-0.03	-0.55*	-0.22	-0.27	-0.02	-0.16	0.27	**0.26**	**0.49**	0.21	0.14	0.09	0.67*	1.00

Table 9 – Pearson correlation between age, anthropometric and ROM data – Right shoulder

	Age	**Weight**	**Height**	**UE**	**FA**	**Hand**	**Flex 1**	**Flex 2**	**Ext 1**	**Ext 2**	**ER 1**	**ER 2**	**Abd 1**	**Abd 2**
Age	1.00	0.16	**-0.31**	0.03	-0.16	-0.21	0.19	-0.04	-0.06	0.04	**0.31**	**0.34**	0.13	-0.06
Weight	0.16	1.00	0.23	0.21	0.12	0.10	0.11	0.09	-0.24	-0.07	0.02	-0.23	-0.10	**-0.31**
Height	**-0.31**	0.23	1.00	0.52*	0.56*	0.50*	0.15	0.20	0.15	0.26	0.05	-0.08	-0.19	-0.10

UE	0.03	0.21	0.52*	1.00	0.52*	0.29	0.08	0.05	0.21	**0.47**	-0.08	0.11	-0.16	**-0.30**
FA	-0.16	0.12	0.56*	0.52*	1.00	**0.47**	0.26	**0.31**	**0.41**	0.56*	-0.16	-0.01	**-0.30**	**-0.34**
Hand	-0.21	0.10	0.50*	0.29	**0.47**	1.00	0.04	-0.04	0.11	0.02	-0.11	0.02	**-0.30**	-0.15
Flex 1	0.19	0.11	0.15	0.08	0.26	0.04	1.00	0.92*	**0.47**	**0.46**	0.24	0.01	0.23	0.05
Flex 2	-0.04	0.09	0.20	0.05	**0.31**	-0.04	0.92*	1.00	**0.42**	**0.49**	0.22	-0.03	0.20	0.09
Ext 1	-0.06	-0.24	0.15	0.21	**0.41**	0.11	**0.47**	**0.42**	1.00	0.79*	-0.03	-0.27	-0.02	0.11
Ext 2	0.04	-0.07	0.26	**0.47**	0.56*	0.02	**0.46**	**0.49**	0.79*	1.00	0.12	0.02	-0.08	-0.05
ER 1	**0.31**	0.02	0.05	-0.08	-0.16	-0.11	0.24	0.22	-0.03	0.12	1.00	**0.44**	0.15	0.21
ER 2	**0.34**	-0.23	-0.08	0.11	-0.01	0.02	0.01	-0.03	-0.27	0.02	**0.44**	1.00	0.24	0.04
Abd 1	0.13	-0.10	-0.19	-0.16	**-0.30**	**-0.30**	0.23	0.20	-0.02	-0.08	0.15	0.24	1.00	0.66*
Abd 2	-0.06	**-0.31**	-0.10	**-0.30**	**-0.34**	-0.15	0.05	0.09	0.11	-0.05	0.21	0.04	0.66*	1.00

- UE: Upper extremity length / FA: Forearm length / Hand: Hand and Finger length
- Flex 1: Flexion ROM, Session 1 / Flex 2: Flexion ROM, Session 2
- Ext 1: Extension ROM, Session 1 / Ext 2: Extension ROM, Session 2
- ER 1: External Rotation ROM, Session 1 / ER 2: External Rotation ROM, Session 2
- Abd 1: Abduction ROM, Session 1 / Abd 2: Abduction ROM, Session 2

5.4 Side dominance and effects of handedness

From Table 6, there is a tendency for the left (non-dominant) shoulder values to be higher than the right (dominant) ones, except for external rotation ROM measurements taken at the 1st session. The greatest absolute difference between sides is observed for the movement of abduction, with greater ROM of about 10° on the left (non-dominant) side. There is also a larger ROM on the left side for the movement of flexion, with a difference of about 5°. These observations are reinforced with the following table (table 10) where the ROM side differences are expressed in % of the absolute ROM averaged across left and right sides. When expressed in %, left side values are greater than right side values in flexion and abduction, while the side differences are smaller and more variable from one day to the next, in extension and external rotation. Thus, side difference values are relatively small in general, ranging from - 5.59% (external rotation, session 1, indicating larger ROM on the right side) to 4.77% (abduction, session 2).

Table 10 - % of difference between both shoulders; positive difference indicates larger values on the left side.

	Session 1	Session 2
Flexion	2.37 ± 9.81	2.72 ± 8.43
Extension	0.44 ± 13.79	3.10 ± 14.61
External Rotation	-5.59 ± 16.65	0.79 ± 18.53
Abduction	4.42 ± 4,85	4.77 ± 5.21

Pearson correlation coefficients revealed that range of motion values between the left and right sides were highly correlated across subjects, with generally good correlations (0.73-0.84) across all the different ROMs at the first session and moderate to good correlations for the second session (0.50-0.82) (table 11). Paired t-test analyses revealed that only abduction ROM showed a significant difference between left and right side measurements, on both days.

Table 11 – Correlation and t-tests between ROM of both shoulders

	Session 1		Session 2	
	Pearson coefficient	T-test (p value)	Pearson coefficient	T-test (p value)
Flexion	0.78	0.36	0.78	0.17
Extension	0.84	0.86	0.82	0.42
External Rotation	0.82	0.12	0.50	0.63
Abduction	0.73	<0.00005	0.65	<0.00005

Finally, in an attempt to assess the relationship between ROM and the level of the right side dominance, measured with the "Edinburgh Handedness Inventory", we computed Pearson correlations (table 12) between the handedness scores obtained and the absolute left-right ROM differences. Although poor to moderate correlations can be observed at session 1 between handedness with extension and external rotation (-0.33 and -0.32 respectively, meaning that more right dominant subjects had more ROM on the left side), none of the other correlation coefficients is high enough to even reach the poor level (=0.25).

Table 12 – Pearson correlation between handedness scores and the left-right ROM differences. Positive ROM dominance indicates larger ROM on the right side. The group mean handedness score was 77.33 ± 16.80, indicating right side dominance.

	Session 1		**Session 2**	
	ROM dominance (**average** ± SD)	**Correlation with handedness score (Pearson coefficient)**	**ROM dominance** (**average** ± SD)	**Correlation with handedness score (Pearson coefficient)**
Flexion	-4.12 ± 24.17	-0.12	-5.58 ± 21.87	-0.17
Extension	0.31 ± 9.46	-0.33	-1.56 ± 10.53	-0.06
External Rotation	2.24 ± 7.61	-0.32	-0.77 ± 8.74	0.17
Abduction	-9.25 ± 10.17	-0.04	-9.68 ± 10.44	-0.01

5.5 Test-retest reliability of shoulder ROM measurements with the Simulator II

The test-retest reliability analyses calculated with Pearson coefficients indicate moderate to excellent day-to-day correlations (0.66-0.92) across all the different ROMs for both shoulders, excluding external rotation; this last movement appears to allow a fair to moderate inter-session reliability (Pearson coefficient range from 0.44-0.56) (Table 13). Paired t-test analyses confirmed that there were no significant differences between measures taken on different days in flexion, extension, external rotation and abduction movements.

Table 13 – Test-retest reliability characteristics of maximal shoulder ROM for all movements

	Left shoulder		**Right shoulder**	
	Pearson coefficient	**T test (p value)**	**Pearson coefficient**	**T test (p value)**
Flexion	0.90	0.45	0.92	0.24
Extension	0.62	0.75	0.79	0.61
External Rotation	0.56	0.28	0.44	0.18
Abduction	0.67	0.60	0.66	0.49

When assessed using ICCs, the test-retest reliability properties of the Simulator II were found to be generally high to excellent, with ICCs above 0.73 in all movements (Tables 14-15); across both sessions and both shoulders, ICCs for the flexion, extension and abduction movements ranged from 0.77 to 0.96. In external rotation, the reliability was found to be moderate to high, with ICC values of 0.73 (left shoulder) and 0.56 (right shoulder). The standard error of measure (SEM) calculated for each ROM varied between 5.72° and 7.67°, proportionally to the maximum range of motion reached for each movement (i.e. highest with flexion and lowest for abduction) (Tables 14-15). The minimal detectable change for the 90th percentile confidence interval (MDC_{90}) varied between 13.34° (abduction ROM, left shoulder) and 17.89° (flexion ROM, right shoulder).

Table 14 – Test-retest reliability characteristics of maximal shoulder ROM for all movements on the left shoulder

	ICC (3,k)	SEM (°)	MDC_{90} (°)
Flexion	0.95	6.65	15.51
Extension	0.77	7.24	16.89
External Rotation	0.73	6.05	14.12
Abduction	0.77	5.72	13.34

Table 15 – Test-retest reliability characteristics of maximal shoulder ROM for all movements on the right shoulder

	ICC (3,k)	SEM (°)	MDC_{90} (°)
Flexion	0.96	7.67	17.89
Extension	0.88	6.05	14.13
External Rotation	0.56	6.31	14.83
Abduction	0.80	6.12	14.29

CHAPTER 6 - DISCUSSION

The general purpose of this study was to report reference data as well as to establish the reliability properties of the Simulator II (BTE technologies™) in measuring shoulder active range of motion in a healthy population of women, to measure the effect of handedness on bilateral shoulder range of motion (ROM) and to report values of clinical relevance of the Simulator II for shoulder active ROM measurements (SEM and MDC_{90th}). Also, other specific objectives were to compare active shoulder ROM of the Simulator II from those of the literature and to assess relationships between age and anthropometric data with shoulder. In the following section the results will be made clear and compared to the literature and their relevance will be addressed.

6.1 Reference data

The general tendency present within our data is that shoulder flexion and abduction range of motion are found to be greater when compared with the two other movements, extension and external rotation (see Table 6). The largest ROM was recorded on average in flexion, with a group mean calculated over both days of 229.77°, followed by abduction, with an overall mean of 208.94°. In extension, the average measure was 73.64°, and finally in external rotation, the average ROM was found to be 49.38°. Furthermore, this trend stays consistent across different sessions and also, it is similar to trends reported in the literature (see Table 7).

There are many factors that come into play to explain the superiority of the flexion and abduction ROM; aside from the contributions of muscles to these actions, probably the most important factor to consider in explaining the variations in shoulder joint ROM across directions is the joint architecture. In this ball and socket joint, the head of the humerus can more easily rotate towards flexion and abduction, and especially in rotation, several tendons and ligaments are designed to prevent excessive movement, which can lead to injuries. The glenohumeral joint has also a loose capsule that is permissive inferiorly which is maybe one of the reasons of the high amplitude and the higher risk of injuries such as the inferior dislocation (Snell, 2006). But, there is a number of bursae (a small fluid-filled sac lined by synovial membrane with an inner capillary layer of slimy fluid (Anderson and Calais-Germain, 1993; McKinley et al., 2000)) present in the capsule especially to give support for the high shoulder mobility (Snell, 2006).

Also, this may be in part due to the greater contribution and / or strength of the muscles that are responsible for these movements. The anterior deltoid and pectoralis major muscles act as agonist and synergist for shoulder flexion. They are both large muscles that are fan-shaped and cover the anterior portions of the shoulder and chest, respectively. In this action, they are aided by the long head of the biceps. All three are among the largest and most powerful muscles of the upper body, which supports the observation of higher ROM in their direction of action. In moving the shoulder into abduction, the main agonist muscle is the middle deltoid; it is a thick, multipennate muscle that is located on the posterior and lateral extremity of the shoulder joint and constitutes an important muscle mass around the glenohumeral joint. These anatomical considerations (location, size) support the observation of large ROM in the direction of abduction. In extension, the main agonistic muscles are the latissimus dorsi and the posterior fibers of the deltoid. The largest of the two is the latissimus dorsi, a triangular-shaped muscle of the lumbar region (lower back), which covers an extensive part of the superficial layer in this region, is as large or even bigger, as the main agonists for flexion, however its insertion on the humerus is smaller and is located farther from the shoulder joint, which could explain the smaller movement amplitude in this direction. Finally, muscles in charge of external rotation are smaller and many, that synergistically contribute to creating this motion as one of their functions. This partly explains why external rotation ROM is not as big as the motions obtained in other directions. Another reason for variations in ROM across directions is possibly how often people are executing these movements in their activities of daily living; for example, flexion and abduction are more related to general work tasks and / or everyday movements; for example, opening a window.

The data collected in the present study are fairly different from the range of corresponding values obtained from past studies (Table 7). The most comparable values with the present study are those of Barnes and colleagues (2001). This study used a 360° clinical goniometer with a 10-inch movable arm on a healthy women population, with standard measurement techniques and a similar experimental protocol, except that subjects were in a supine position rather than seated. For movements of extension and abduction, on the dominant and non-dominant arm, authors presented ROM values equivalent, albeit slightly smaller, than values recorded in the present study (extension: approx. 8° smaller, abduction: approx. 15° smaller). This might be caused by the different test positions (supine vs. seated). Moreover, in their study the age range of the participants was larger (4-70) than in the present one (20-52); since ROM has been shown to be reduced in the elderly (Allander et al., 1974; Barnes et al., 2001), the inclusion of subjects aged 50–70 years may have therefore contributed to smaller ROM in the Barnes et al. study.

In other studies (AAOS, 1965; Boone and Azen, 1979; Walker et al., 1984; Greene and Wolf, 1989; Sabari et al., 1998; Boon and Smith, 2000; Awan et al., 2002; Lomond et al., 2009), most ROM data reported are slightly dissimilar; values are most of the time smaller than the ones reported here especially for shoulder flexion, extension, and abduction movements. Most of the findings from the literature are not directly comparable to the results observed in the present study due to various reasons outlined in the following section.

Firstly, sample sizes of the reported studies vary greatly and are sometimes smaller (Greene and Wolf, 1989), approximately the same (Sabari et al., 1998; Barnes et al., 2001; Lomond et al., 2009) or larger (Boone and Azen, 1979; Walker et al., 1984; Boon and Smith, 2000; Awan et al., 2002). Moreover, the dissimilarities could have come from the sample characteristics; no other study assessed women only, none assessed the exact same age range (20 to 52) and very few reported data from healthy people only. Indeed, studies assessed either genders (Greene and Wolf, 1989; Sabari et al., 1998; Boon and Smith, 2000; Awan et al., 2002; Lomond et al., 2009) or only male subjects (Boone and Azen, 1979). Since several studies have reported greater ROM in women, it makes sense that women's only samples such as ours would report ROM values slightly higher than the ones reported with gender-balanced or male samples. With regards to sample age, there is large variation in the literature, with some studies using approximately the same age range as the one used in the present study (Greene and Wolf, 1989; Walker et al., 1984; Sabari et al., 1998; Barnes et al., 2001; Lomond et al., 2009), younger (Boon and Smith, 2000; Awan et al., 2002) or older (Boone and Azen, 1979; Sabari et al., 1998; Barnes et al., 2001), and most studies agreed that young (before adulthood) and old (beyond 65) age has an effect on ROM (Allander et al., 1974; Barnes et al., 2001). Thus, age could be a credible explanation for the differences in ROM between ours and other studies. Finally, the health and fitness status of the subject sample is another important characteristic that could affect ROM measurements. There is some variation in the literature on this aspect as well, with some studies having assessed healthy normal subjects (without musculoskeletal disease) (Boon and Azen, 1979; Greene and Wolf, 1989; Walker et al., 1984; Barnes et al., 2001), athletes (Boon and Smith, 2000; Awan et al., 2002), specific diseases (Lomond et al., 2009: neck-shoulder pain) and / or different populations in the same sample (Sabari et al., 1998).

Moreover, the exact definition of each status was oftentimes lacking, making the interpretation of the data more difficult.

Aside from the subject characteristics, differences might have come from the different methodologies used in the literature. The main contrast between the literature and our study might be due to the equipment. Except from the Lomond and colleagues study, no scientific study previously reported shoulder ROM measures taken with the Simulator II, supporting the importance of the present study. Most previous studies reported values taken with a goniometer (Boone and Azen, 1979; Walker et al., 1984; Greene and Wolf, 1989; Sabari et al., 1998; Boon and Smith, 2000; Barnes et al., 2001) and the rest used an inclinometer (Awan et al., 2002) and a custom device (Ortho Ranger, Greene and Wolf, 1989). In addition, the subject position varied from one study to another. Some studies tested subjects while they were seated (Walker et al., 1984; Sabari et al., 1998; Lomond et al., 2009) and in others, subjects were either standing or lying down, in a supine position (Boone and Azen, 1979; Walker et al., 1984; Greene and Wolf, 1989; Sabari et al., 1998; Boon and Smith, 2000; Barnes et al., 2001; Awan et al., 2002). From the literature, it appears that ROM measured in a supine position could be generally smaller than that taken in a seated position, which also supports the fact that values collected in the present study are generally larger than in others. Related to this factor, not all studies measured ROM from a neutral (anatomical) position. For example, the largest discrepancy between our data and that of the literature is for external rotation ROM, with the Boon and Smith (2000) and the Awan et al. (2002) studies reporting much larger values (almost twice the ones reported here). Subjects from both studies were positioned supine with the arm at 90° of glenohumeral abduction, whereas we recorded from a seated position with a 45° of glenohumeral abduction, as recommended in the Simulator II user manual.

Another cause for variation can be attributed to whether ROM trials were performed actively or passively. Several studies, including the two aforementioned, recorded passive ROM (Sabari et al., 1998; Boon and Smith, 2000; Barnes et al., 2001; Awan et al., 2002) and approximately as many recorded ROM trials achieved actively by the subject (Boone and Azen, 1979; Walker et al., 1984; Greene and Wolf, 1989; Sabari et al., 1998; Barnes et al., 2001; Lomond et al., 2009). Thus, variation could have occurred because passive shoulder rotation movement is known to produce larger ROM than for movement produced actively by the subjects themselves.

Finally, part of the general variability in data found in literature can also be partly explained by variability in the experimental procedures followed. For example, Barnes et al. (2001) only tested every movement once, whereas Walker et al. (1984) tested every motion twice, and Greene and Wolf (1989) made 3 measurements, similarly to our study. Moreover, Walker and colleagues also used a measurement sequence that minimized the positional changes by the subject, whereas Sabari and colleagues (1998) measured every motion eight times in a random order. Taking multiple measurements is preferred in order to obtain a stable measurement, and a randomized sequence is more appropriate in order to avoid learning or fatigue effects; thus, both factors can also play parts in inducing variability in measurements from one study to the next.

6.2 Relationships between age, anthropometric data and active shoulder ROM

Our working hypotheses were that there were going to be strong relationships between shoulder ROMs, age, and anthropometric characteristics (arm length segments, height, weight). We did observe some correlations between segment lengths and ROM; there were moderate to good correlations between session two right extension ROM and forearm segment lengths and between session 2 left / right abduction ROM and weight (see Table 8 and 9). However, the fact that these correlations were only observed on one day and that there is good correlation between measurements from session one to session two suggests that these correlations may be attributable to chance variability in the sample, likely related to sample size. In all other cases, relationships between segment lengths and ROM were low or nonexistent. From our results, it appears that age, height and weight do not really influence the subjects' ROM results. This is important information for clinicians using the Simulator II in that for subjects with similar age characteristics than in our study, we can expect that age, height and weight would induce negligible error on the ROM measurements taken. Finally, most of the age and anthropometric data were well correlated between each other as was expected, as were some ROM measurements with others although these were not always systematic.

6.3 Side dominance and effects of handedness

In the present study, in general, left and right side measures were equivalent with exception of abduction ROM. The reasons for this significant difference (abduction ROM) are unclear at this point. This is likely related to some methodological issues whereby the chair positioning was not exactly the same, with respect to the exercise head, or the straps used to stabilize subjects were not of the same effectiveness on both sides. However, our results may also, at least in part, reveal a true superiority of ROM from the non-dominant side in abduction, as it has sometimes been suggested in the literature. A follow-up study with a larger sample size is needed to shed light into this question. Moreover, Pearson correlation coefficients revealed that range of motion values between the left and right sides were highly correlated across subjects, with generally good correlations (0.73-0.84) across all the different ROMs at the first session and moderate to good correlations for the second session (0.50-0.82) (table 11), indicating that people with larger ROM displayed it from both sides. Thus, our results support the pertinence of using the contralateral side as reference when assessing shoulder ROM deficits in the clinical setting.

Finally, in an attempt to determine how handedness may affect bilateral differences in ROM, we computed Pearson correlations (table 12) between the handedness scores obtained and the left-right differences in ROM values. Results show that none of the correlations between handedness and left-right ROM difference, in any of the movement directions, are high; thus, it seems that the degree of right-handedness (all our subjects were right handed), or the strength of the tendency to use the right arm in everyday tasks, doesn't affect the ROM differences between left and right sides, lending support against the previous hypothesis that repeated use of a limb is somehow related to the observed ROM of that limb.

6.4 Reliability of the shoulder ROM measurements with the Simulator II

Currently, with all the new measurement tools available in the clinical setting, it is important to report their test-retest reliability to support their repeated use. The reliability of our instrument, the Simulator II, in measuring shoulder ROM on two separate days has been demonstrated to be high, with ICCs ranging from 0.77 to 0.96 for shoulder flexion, extension and abduction ROM. The only movement that appeared to be less reliable than the other ones is external rotation (moderate correlations of 0.56 and 0.73). Other studies also found that the shoulder ROM measurement with the most considerable variability compared to other movements was external rotation (Walker et al., 1984; Greene and Wolf, 1989; Awan et al., 2002). In our study, this between-day variability may have been due to the fact that some subjects use more compensatory motions from their trunk and others from their actual shoulder to execute the motion, and some subjects had difficulty conceptualizing the movement of rotation itself as performed in our study, which is not similar to movements accomplished in everyday activities.

Also, our choice of task to assess shoulder external rotation in our protocol (see Chapter 4), i.e. not starting from anatomical position, elbow flexed, likely produced a movement that was not pure shoulder rotation but rather a combination of shoulder motion with slight forearm supination, which likely induced variation in our measurements. External rotation ROM movement has small amplitude, involves several muscles (serratus anterior, trapezius, infraspinatus and teres minor) and is more complex in its execution, and as a consequence, it is not surprising that there is considerable inter-trial variability in the movement. Our data suggests that, excluding the external rotation tasks, test-retest reliability was similar for movements with the right shoulder (Pearson = 0.66 to 0.92) compared to the left one (Pearson = 0.62 to 0.90). If this is indeed the case, it follows that in a clinical setting, true between-session improvements can be detected with the same confidence from both shoulders. This is supported by our results comparing intra-class correlation coefficients, standard error of measurements and minimal detectable change (see next paragraph) between sides; larger studies with more subjects, and particularly with injured individuals, must be performed in order to verify this interpretation. Nevertheless, we can say that measurements taken by the Simulator II in healthy right-handed women subjects can be estimated to be reliable across trials and sessions. This is very important practical information in the clinical setting, where shoulder ROM measurements, which are often related to the disability state of a patient, are taken repeatedly during the rehabilitation process. Thus, our study shows that if used appropriately, with the exception of the shoulder external rotation, the Simulator II can be trusted to take reliable shoulder ROM measurements and to reflect the integrity of the shoulder amplitude.

Since the SEM indicates how much a score will vary with repeated measures (Hanna et al., 2005) and the MDC_{90} represents the minimal amount of change that is not likely to be due to chance variation in measurement (Haley and Fragala-

Pinkham, 2006), both of these measures are important characteristics to take into account when performing a test-retest evaluation, especially in a clinical context. The SEM and MDC_{90} values reported in this study were small and approximately the same for left and right shoulders (see Table 14 and 15). Moreover, the SEM produced for each motion was relatively proportional to the mean ROM for each movement. When compared to SEM and MDC_{90} values reported in the literature (SEM: Boon and Smith, 2000; SEM and MDC_{90}: Lomond et al., 2009), our values are smaller than the ones reported by Boon and Smith, which is not surprising since their measurements were taken with a goniometer which requires manual interaction with the patient in taking the measurements, which supports the belief that the Simulator II is a more reliable ROM assessment tool.

However, both our SEM and MDC_{90} values are larger than those reported in the Lomond study. This could be due to the fact that the patients with shoulder pain assessed in that study also displayed generally less ROM and from the equations, it follows that we should also expect SEM and MDC_{90} values to be lower. The SEM and MDC_{90} values hold practical significance in a clinical context and are essential in interpreting the real value of a change measured with the Simulator II. For example, for a person performing a flexion movement of 232.18° (corresponding in our case to the average of both sessions for the left shoulder), since the corresponding SEM is 6.65°, in a follow-up evaluation, if the individual obtains an amplitude value of 225.53° or less, or 238. 83° or more, this would indicate an authentic change in the shoulder flexion ROM in that subject. Thus, clinically, the average range of motion values are much more meaningful when accompanied with the corresponding SEM and MDC_{90} values, so as to make the appropriate interpretations of the data and effective evidence-based clinical decisions. As such, the interpretation of our left-right side difference in abduction measurements can be made more accurately in light of the SEM and MDC_{90} values reported for abduction measurements. Indeed, we show a significant left-right side difference in abduction, which is bigger than the SEM by about 4-5 degrees, suggesting that this difference is not due to errors in the measurements.

However, this side difference is smaller than the MDC_{90}, which suggests that this difference is smaller than the expected chance variation in measurements taken with the Simulator II. Thus, the measured left-right differences in abduction ROM may be considered as a true difference but not a clinically meaningful one.

CHAPTER 7 – CONCLUSION

7.1 Summary

The literature has shown that there is a need for objective measurement tools that can be used to assess shoulder ROM. This research has confirmed some of our hypotheses: the reference data that we obtained are quite similar with the results from the literature, were not associated with age or anthropometric characteristics, were similar between left and right sides except for abduction, and were independent from handedness scores. Moreover, the Simulator II is a reliable device for shoulder ROM measurement; the measurements obtained for three movements (flexion, extension and abduction) demonstrated high to excellent reliability, with ICCs above 0.77. For external rotation, the Simulator II demonstrated moderate to high reliability (0.56-0.73). Aside from the easiness to use and the possibility for obtaining objective measurements that are independent from manipulation from the clinician, the SEM and MDC_{90} values reported in this work confirm that the Simulator II is a more reliable tool that standard goniometers (as reported in the literature).

Moreover, our findings will provide important information to clinicians in evaluating the clinical meaningfulness of their measurements. The comparison between both shoulders (dominant and non-dominant) has confirmed previous studies; our synthesis establishes that there are no significant differences between ROM of dominant vs non-dominant sides in a right-handed population, with the exception of a difference found for abduction ROM, which is likely explained by methodological issues in our protocol. However, although the measured left-right side difference was bigger than the calculated SEM for abduction, it is smaller than the MDC_{90}, which suggest that this left-right side difference in abduction is smaller than the expected chance variation in measurements taken with the Simulator II. Thus, the measured left-right differences in abduction ROM may be considered as a statistical difference but not a clinically meaningful one. Moreover, we are the first to show that general handedness (the strength of the tendency to use one arm over the other in everyday life) has no effect on bilateral ROM differences. We are also the first to present shoulder ROM measurement properties exclusively from a sample of women, providing gender-specific data that can be used in the clinical setting as reference values to assess and treat female patients.

7.2 Future directions

Our results open the way for interventions with the Simulator II, by providing reference values for female right-handed adults and in demonstrating reliability of the system in assessing shoulder ROM. The Simulator II is commonly used in clinical settings, mainly for work simulations; however our study supports its additional use as an objective device that can be easily used to measure shoulder ROM. To thoroughly assess the feasibility of using the Simulator II in measuring shoulder ROM in the clinical setting, future studies should compare values from healthy subjects to those of various pathological populations. Further to our presentation of data on the clinical meaningfulness of shoulder ROM values (SEM and MDC_{90}), the Simulator II can now be used to train people to increase their amplitude of motion while they recover normal function after injury. With caution that is consistent with our findings, our results generally support the notion that the Simulator II can be effective not only in quantifying shoulder ROM but also in being used as training tool, making it a more complete and useful piece of equipment for clinicians to use.

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APPENDIX A

Comité d'éthique de la recherche
des établissements du CRIR

Montréal, le 30 mai 2008

Madame Julie Côté, Ph. D.
Hôpital juif de réadaptation
3205, Place Alton-Goldbloom
Laval, Québec
H7V 1R2

Centre de réadaptation Lucie-Bruneau
Centre de réadaptation Constance-Lethbridge
Hôpital juif de réadaptation
Institut Nazareth et Louis-Braille
Institut Raymond-Dewar
Institut de réadaptation de Montréal

Partenaires
Centre de réadaptation Estrie
Centre de réadaptation La Ressourse
Centre de réadaptation en déficience physique Le Bouclier

N/réf. : CRIR-364-0508

Madame Côté,

Veuillez trouver, ci-joint, une copie du certificat d'éthique qui a été décerné pour votre projet :

« Effets de la fatigue et de lésions au cou ou à l'épaule reliées au travail sur la coordination du mouvement et la stabilité de la posture lors de tâches répétitives du bras : validation test-retest des mesures de fonction du bras».

Ce certificat est valable pour un an. Le CÉR demande à être informé de toute modification qui pourrait être apportée au projet de recherche mentionné ci-dessus (Formulaire M).

De plus, nous vous demandons de contacter la personne suivante afin de l'aviser du début de votre projet de recherche :

Julianna Guy HJR (450) 688-9550,

Recevez, Madame Julie Côté, l'expression de nos meilleures salutations.

Anik Nolet

Me Anik Nolet
Coordonnatrice à l'éthique de la recherche
des établissements du CRIR

AN/fm

p.j.: Certificat d'éthique et documents approuvés

Comité désigné en vertu de l'article 21 du Code civil du Québec

2275, avenue Laurier Est
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T (514) 527-4527 (2643)
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Comité d'éthique de la recherche
des établissements du CRIR

Certificat d'éthique

Par la présente, le comité d'éthique de la recherche des établissements du CRIR (CÉR) atteste qu'il a évalué, par voie accélérée, le projet de recherche **CRIR-364-0508** intitulé:

« Effets de la fatigue et de lésions au cou ou à l'épaule reliées au travail sur la coordination du mouvement et la stabilité de la posture lors de tâches répétitives du bras : validation test-retest des mesures de fonction du bras ».

Présenté par: **Julie Côté, Karen Lomond, Evelyne Boulay**

Le présent projet répond aux exigences éthiques de notre CÉR. Le Comité autorise donc sa mise en œuvre sur la foi des documents suivants :

- Lettre de présentation datée du 20 mai 2008 ;
- Formulaire A daté du 20 mai 2008 ;
- Grilles d'évaluation scientifique datées du 22 mai 2008 ;
- Réponses de madame Julie Côté au comité d'évaluation scientifique ;
- Protocole de recherche intitulé « Effets de la fatigue et de lésions au cou ou à l'épaule reliées au travail sur la coordination du mouvement et la stabilité de la posture lors de tâches répétitives du bras : validation test-retest des mesures de fonction du bras » (version telle qu'approuvée par le CÉR le 30 mai 2008) ;
- Lettre et formulaire d'évaluation de la convenance institutionnelle de l'Hôpital juif de réadaptation, datés respectivement du 29 mai 2008 et du 23 mai 2008, mentionnant l'acceptation du projet sur le plan de la convenance institutionnelle ;
- Formulaire de consentement – Sujets sains, en version française et anglaise.

Ce projet se déroulera dans le site du CRIR suivant : **Hôpital juif de réadaptation.**

Ce certificat est valable pour un an. En acceptant le présent certificat d'éthique, le chercheur s'engage à :

1. Informer, dès que possible, le CÉR de tout changement qui pourrait être apporté à la présente recherche ou aux documents qui en découlent (Formulaire M) ;
2. Notifier, dès que possible, le CÉR de tout incident ou accident lié à la procédure du projet ;
3. Notifier, dès que possible, le CÉR de tout nouveau renseignement susceptible d'affecter l'intégrité ou l'éthicité du projet de recherche, ou encore, d'influer sur la décision d'un sujet de recherche quant à sa participation au projet ;
4. Notifier, dès que possible, le CÉR de toute suspension ou annulation d'autorisation relative au projet qu'aura formulée un organisme de subvention ou de réglementation ;

5. Notifier, dès que possible, le CÉR de tout problème constaté par un tiers au cours d'une activité de surveillance ou de vérification, interne ou externe, qui est susceptible de remettre en question l'intégrité ou l'éthicité du projet ainsi que la décision du CÉR ;

6. Notifier, dès que possible, le CÉR de l'interruption prématurée, temporaire ou définitive du projet. Cette modification doit être accompagnée d'un rapport faisant état des motifs à la base de cette interruption et des répercussions sur celles-ci sur les sujets de recherche ;

7. Fournir annuellement au CÉR un rapport d'étape l'informant de l'avancement des travaux de recherche (formulaire R) ;

8. Demander le renouvellement annuel de son certificat d'éthique ;

9. Tenir et conserver, selon la procédure prévue dans la *Politique portant sur la conservation d'une liste des sujets de recherche*, incluse dans le cadre réglementaire des établissements du CRIR, une liste des personnes qui ont accepté de prendre part à la présente étude ;

10. Envoyer au CÉR une copie de son rapport de fin de projet / publication.

Me Michel T. Giroux
Président du CÉR

Date d'émission
30 mai 2008

APPENDIX B

Consent form
(Control)

1 - Title of project

Effects of Fatigue and Occupational Neck-Shoulder Disorders on Movement Coordination and Postural Stability in Repetitive Movements of the Upper Limb: test-retest validation of arm functional measures

2 - Researchers in charge of project

Julie Côté, Ph.D. Assistant professor, Department of Kinesiology and Physical Education, McGill University, (514) 398-4184 ext. 0539

Karen Lomond, Ph.D. Kinesiology student, Department of Kinesiology and Physical Education, McGill University, (514) 907-5380

Evelyne Boulay, master's student, Department of Kinesiology and Physical Education, McGill University, 450-688-9550 ext. 4827

3 - Project description and objectives

The general objective of this research is to evaluate the coordination between joint movements, muscle function, and postural stability before, during and after a fatiguing, repetitive arm task. The arm task will be performed from either a seated or a standing position. Our goal is to understand and quantify the way in which the body adapts to the fatigue generated in repetitive tasks. Thirty healthy subjects will be recruited to participate in this study. A group of thirty subjects diagnosed with an occupational neck-shoulder disorder will also be recruited. We will then compare posture, movement, and muscle characteristics of both healthy and injured groups during the task. Using this information, we hope to identify possible early indicators of fatigue and of occupational neck-shoulder disorders. This information could be useful in adapting repetitive work tasks to avoid fatigue and occupational neck-shoulder disorders.

An additional group of healthy subjects will be recruited to obtain normative values of shoulder function. This data will serve as reference to evaluate the impairment of subjects with neck-shoulder disorders.

4 - Nature and duration of participation

This research protocol will be administered at the research center of the Jewish Rehabilitation Hospital (JRH). My complete participation in this protocol requires that I participate to two sessions for approximately thirty minutes each time. During each testing session, the researcher will record my upper body forces and motion.

During each session, I will perform several tasks with each shoulder. I will flex my arm forward as high as I can, I will raise it to the side as far as I can, I will push forward as strongly as I can for 5s, I will push back and forth for 10s as powerfully as I can, I will elevate my shoulder as strongly as I can, and I will flex my arm forward as strongly as I can. None of these procedures is invasive. I will be allowed sufficient rest between efforts and I will be able to interrupt the protocol anytime I want.

5 - Advantages associated with my participation

I will not personally benefit from any advantage by participating in this study. However, my participation will contribute to the science of human movement and will provide further understanding of the effects of fatigue and injury on movement.

6 - Risks associated with my participation

None of the techniques used are invasive. I understand that my participation in this project does not put me at any medical risk.

7 - Personal inconveniences

The duration of the protocol (approximately thirty minutes) might be an inconvenience for me. Any effort will be made by the investigators to accommodate my availability when scheduling the testing sessions. Also, I may experience some fatigue during the protocol, which may cause some neck and shoulder muscle tenderness or stiffness. These symptoms should dissipate within 48 to 72 hours after the protocol.

8 - Access to my medical file

Access to my medical file is not required for this study.

9 - Confidentiality

All the personal information collected for this study will be codified to insure confidentiality. Information will be kept under lock and key at the research center of the Jewish Rehabilitation Hospital by one of the persons responsible for the study for a period of five years. After this period, data will be destroyed. Only the people involved in the project will have access to this information. If the results of this research project are presented or published, no identifying information will be disclosed.

10 - Questions concerning the study

The researchers present during the testing should answer my questions concerning the project in a satisfactory manner.

11 - Withdrawal of subject from study

Participation in the research project described above is completely voluntary. I have the right to withdraw from the study at any moment, without penalty. Should I withdraw from the study, all electronic and written documents concerning myself will be destroyed.

12 - Responsibility

By accepting to enter this study, I do not surrender to my rights and do not free the researchers, sponsor or the institutions involved from their legal and professional obligations.

13 - Monetary compensation

No monetary compensation will be offered to me for my participation.

14 - Contact persons

If I need to ask questions about the project, signal an adverse effect and/or an incident, I can contact at any time Karen Lomond, Ph.D. candidate, at (514)907-5380 or Julie Côté, assistant professor at the Department of kinesiology and physical education of McGill University at (450) 688-9550 extension 4813. For further questions related to this study, I may also contact M. Michael Greenberg at (450) 688-9550, extension 232, local commissioner for the quality of services at the JRH.

Also, if I have any questions concerning my rights regarding my participation to this research project, I can contact Mme. Anik Nolet, Research ethics co-ordinator of CRIR at (514) 527-4527 ext. 2643 or by email at: anolet.crir@ssss.gouv.qc.ca.

CONSENT

I declare to have read and understood the project, the nature and the extent of the project, as well as the risks and inconveniences I am exposed to as described in the present document. I had the opportunity to ask all my questions concerning the different aspects of the study and to receive explanations to my satisfaction.

I, undersigned, voluntarily accept to participate in this study. I can withdraw at any time without any prejudice. I certify that I have received enough time to take my decision.

A signed copy of this information and consent form will be given to me.

NAME OF PARTICIPANT (print): ______________________________

SIGNATURE OF PARTICIPANT: ______________________________

SIGNED IN ________________________, on __________________, 20_____.

COMMITMENT OF RESEARCHER

I, undersigned, ________________________________ , certify

- **(a) having explained to the signatory the terms of the present form ;**
- **(b) having answered all questions he/she asked concerning the study ;**
- **(c) having clearly told him/her that he/she is at any moment free to withdraw from the research project described above; and**
- **(d) that I will give him/her a signed and dated copy of the present document.**

____

Signature of person in charge of the project or representative

SIGNED IN __________________, on ___________________________ 20__.