Analysis of Upper Body Measurement Change Using Motion Capture

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Abstract

An understanding and clear descriptions of the human body in motion is important to achieve good fit of garments (Bye et al, 2006; Gill, 2009). However, to date there is still limited research on measuring the dynamic body and its application to clothing, and no previous studies have focused on measuring the dynamic body across body sizes.

The purpose of the research was to explore the research method to examine body measurements using the motion capture system. This study tested the accuracy and reliability of a motion capture system in measuring a human body in comparison to the 3D body scanner. The second purpose was to investigate the body measurement changes in motion and to examine the measurement changes in motion across body sizes.

The exploratory research was developed based on the framework for micro and macro levels of fit. The methods for this study were developed to examine body measurements using a motion capture system. The upper body movements in relation to the shoulder girdle were selected for a motion test for this study. The selected motions were the arm rotation and golf swing. Measurements were selected based on their application to pattern development.

A total of the 25 women participated in this study. All of them participated in the golf swing test; six were the golf team members and 19 were novices. Of the 25 participants, 19 participated in the arm rotation test. Markers, needed for the optical motion tracking system, were placed at locations on the body corresponding to the selected measurements. Once the markers were attached, the participants were scanned in a natural and relaxed posture using the body scanner, and then their movements were recorded three times using a motion capture system. The quantitative data from the body scanner and motion capture system were analyzed using descriptive statistics, a paired t-test, and an independent t-test.

Descriptive analysis of the body measurement change in the two different motion tests in this study indicated that upper body measurements increased or decreased corresponding to the shoulder joint and scapula movement. The shoulder and

back arc at the armpit showed the greatest measurement change. The back arc at the armpit increased the most, while the shoulder width decreased the most in the upper body during the motion that involved the arm and torso movement. When the participants performed the arm rotation motion, the shoulder width (-38.45%), back width (16.08%), and back arc at the armpit (27.69%) showed the most change. The locations that changed measurements the most were the same as the results from the golf swing test. When the participants performed the golf swing motion, the shoulder width (-14.47%), back width (15.58%), and back arc at the armpit (20.65%) changed the most. An independent t-test indicated that the measurement changes in the golf swing test were different between the novice and expert golfers due to their golf swing poses. There was a significant difference in the decreases of the shoulder width, and the increases of the lower back arc, right side length, and left diagonal on the back of the body.

The results of this study suggest that the measurement changes and percent changes increased as body size increased in two different motion tests.

This study suggests that the motion capture system can be successfully used as a body measurement method. The motion capture system can be a reliable method to collect body measurements and to examine the body measurement changes in motion. The motion capture system allowed considering variations in continuous movements among individuals across sizes for dynamic anthropometric studies.

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CHAPTER ONE: INTRODUCTION

The way in which the body is measured is important to garment fit, in particular, for garment pattern development. Measuring the body is the first step in the development of a garment pattern, so a reliable and accurate body measurement system is critical to provide a description of the body, which varies in shape, posture, and movement (Bye, LaBat, & Delong, 2006). The measurement and quantification of the body is complicated as the human body is a complex form with many variations. Several body measurement methods, such as the linear measurement method and the somatometry method, have been explored in an attempt to adequately characterize the three-dimensional body form and have been applied to pattern development methods to provide better fit.

An understanding and clear descriptions of the human body in motion have been considered as the next frontier in achieving good fit of garments (Bye et al, 2006; Gill, 2009). The human body is active and the surface of the body changes, even during a simple motion. As the body moves, the body expands and contracts. The garment may be distorted to accommodate the expansion and contraction of the body; thus, the body changes that occur during movement could affect the fit of the garment.

Clothing designers need to know the amount and the location of body measurement changes as the body moves because the garment does not only fit a static body, but a body in many positions (Watkins, 1995). Previous studies have been conducted to analyze body movement and quantify body measurement change in active postures. The body surface measurement changes were mainly considered to examine the expansion and contraction of the body. Analysis of body measurement changes was useful for the development of patterns; in particular, it contributed to the determination of ease. Ease is a value added to a body measurement for comfort and freedom of movement. Huck, Maganga, and Kim (1997) found that clothing ease can be determined by using body movement analysis. In their study, the needed crotch ease in a one–piece protective garment was determined by changes to total crotch length or back length for different body movements. Choi and Ashdown (2011b) identified pants with an ideal ease amounts using the measurements from lower body surface changes in a sitting and standing posture. Additionally, Wang, Mok, Li, and Kwok (2009) indicated that there is an interaction between joint movement, body measurements, and clothing ease. It was found that the level and placement of ease can be determined by changes in human body measurements with different joint movements.

Although several studies have suggested associations between body movement and garment fit, to date there is still limited research on measuring the dynamic body and its application to clothing. Previous studies were limited to measuring the body in several selected postures, not in motion. Little research has been done on the body measurement changes in continuous motion. Moreover, to the best of our knowledge, no previous studies have focused on the difference in body surface measurements across body sizes.

Therefore, the purpose of this study was to explore a research technique to examine the body measurement changes in motion using a motion capture system and to examine the measurement changes in motion across body sizes.

Ultimately, a goal of this study is to provide further insight into measuring the dynamic body to produce garments with good fit. An investigation of body measurement in motion will provide anthropometric data for determination of ease to be used in pattern development; it will be empirical evidence regarding the ease allowances and how they are determined. Measuring the body in motion using the motion capture system may be especially useful for designing sportswear or functional clothing that requires measuring human movements for a variety of activities.

CHAPTER TWO: LITERATURE REVIEW

In order to explore a research method to examine the body measurement changes in motion and to examine the measurement changes in motion across body sizes, a review of literature was necessary to understand the concept of garment fit, body measurement methods, and garment fit and movement.

Garment Fit

The concept of garment fit is based on an understanding of the relationship between the human body and the garment. The relationship of the body to the garment is called "apparel fit" (Bye, LaBat, McKinney, & Kim, 2007; Ashdown & DeLong, 1995). Berry (1963, p.314) defined fit as a "correspondence in three dimensional form and in placement of detail between the figure and its covering to suit the purpose of the garment, to provide for activity, and to fulfill the intended style."

Fit is influenced by several factors contributing to clothing appearance and comfort. Analysis of clothing fit is a process in which the relationship between the human body and clothing is assessed to judge the appearance of the garment on the body and the wearers' comfort perception. Fit analysis should be conducted in such a way that it will achieve a good and accurate fit, pleasing style lines, and customer satisfaction. Apparel researchers have developed methods for judging apparel fit based on responses from expert judges, a visual analysis of the garment on the body, and on the wearers' subjective perception of the garment. Elements of fit can be categorized as physical comfort, physiological comfort, psychological comfort, and visual fit. The visual fit is judged by expert panels based on fit criteria and the comfort assessment is based on the wearers' preference and perception.

Comfort is a key parameter in clothing. Slater (1985) defined comfort as a pleasant state of physiological, psychological, and physical harmony between a human being and the environment. First, psychological comfort depends on the aesthetic appearance of the garment. Psychological factors affecting comfort include flattering garment style, proper fit, fashion, suitability for an occasion, and body image/body cathexis. Second, physiological comfort relies on the mechanical interaction between a piece of clothing and the body. It has two aspects: "the local feel" of the fabric against the skin and "the global feeling" about the garment (Li & Dai, 2006). The local feel refers to tactile comfort including itchiness and roughness. The global feeling relates to pressure comfort including heaviness and tightness. Third, physical comfort is also associated with the interaction between a piece of clothing and the physical body. While physiological comfort relates to the skin, physical comfort relates to body size, dimension, posture, and movement. According to Ashdown and Dunne (2006), a garment's fit involves the interactions of multiple factors, including the size, proportion and posture of the wearer, and the dimensions and drape of the garment.

Visual fit generally contains five elements: grain, set, line, balance and ease (Erwin & Kinchen, 1964). The grain should run parallel to the center front and center back of the garment. Good set refers to a smooth fit with no undesirable wrinkles, and the lines of the clothing follow the silhouette and circumference lines of the body. Balance indicates that the piece of clothing appears symmetrical from side to side and front to back. Ease is defined as the extra fabric needed for comfort, ease of movement, and style beyond body measurements. Adequate fitting ease is required to provide comfort and allow room for movement with design ease for garment style. Ease is especially important in defining garment fit because it affects the physical comfort and intended style of the garment (visual fit) at the same time.

Many apparel researchers have focused on the ease in garment fit research. Jay (1969) defined ease as the difference between the pattern and body dimensions and as a crucial component of achieving good fit and comfort. Ease is an additional amount added to the body measurements at certain critical points on the pattern. During pattern construction, a small amount of ease must be added to the anthropometric values for comfort and freedom of movement (Gordon, 1986). Ease is not just a simple addition to the dimensions, but depends on many factors including body movement, fabric characteristics, comfort preferences, and garment style (Fan, Yu, & Hunter, 2004; Chen, Zeng, Happiette, Bruniaux, Ng, & Yu, 2008).

Page (2003) defined ease as the difference between actual body measurements and the finished measurements of the garment. Ease directly affects garment fit, appearance and comfort. There are two types of ease: wearing ease and design ease. The amount of ease allowed for movement is known as the wearing ease, or movement ease, or dynamic ease. Wearing ease follows the basic rule that the wearer must be able to move, bend, breathe, sit, raise arms and walk without the garment being over pulled, pinched, binded, stretched, or strained beyond a natural relaxed position (Myers-Mcdevitt, 2004). This ease typically adds two inches to the bust, waist, hip, and other key circumference points to any basic women's block. Wearing ease is critical in garment fit; incorrect wearing ease causes unflattering wrinkles and limits movement. Because garments should provide a certain degree of comfort and movement, it is important to know the wearing ease allowances (Reich & Otten, 1991). Another type of ease is design ease, which is the amount of ease added to the basic block in addition to wearing ease. Design ease takes layering needs into consideration and is dependent on the type of fabric used.

There are key points where the amount of ease directly affects fit: bust, waist, hip, arm circumferences and armcye. The Misses' sizing system suggests ease allowances for tops based on the garment silhouette. A close fitting silhouette requires 0 - 2 7/8 in; a fitted silhouette requires 3 - 4 in.; a semi-fitted silhouette requires 4 1/8 - 5 in.; a loose-fitting silhouette is 5 1/8 - 8in. Myers-McDevitt (2004) specifically suggested ease allowances for the garment silhouette (see Table 1).

Table 1. Ease Allowances for the Garment Silhouette Suggested by Myers-McDevitt (2004)

	Close-fitting	Fitted	Semifitted	Loose fitting	Oversized
Bust	1/2 – 2 in.	2 – 4 in.	4 – 5 in.	5 – 8 in.	Over 8 in.
Waist/Hip	1/2 – 2 in.	2 – 3 in.	3 – 4 in.	4 – 6 in.	Over 6 in.
Waistband	1/4 – 1/2 in.	1/2 – 3/4 in.	3/4 – 1 in.	1 – 2 in.	Over 2 in.
Armhole	1 – 2 in.	2 – 3 in.	3 – 4 in.	4 – 5 in.	Over 5 in.
Upper Arm /Sleeve	1 – 2 in.	2 – 3 in.	3 – 4 in.	4 – 5 in.	Over 5 in.
Elbow	1/2 – 1 in.	1 – 2 in.	2 – 3 in.	3 – 4 in.	Over 4 in.
Wrist	1/2 in.	1/2 – 1 in.	1 – 2 in.	2 – 3 in.	Over 3 in.
Shoulder Seam	0 – 1/4 in.	1/4 – 1/2 in.	1/2 – 1 in.	1 – 1 1/2 in.	Over 1 1/2 in.
Across Back	1/2 – 3/4 in.	3/4 – 1 1/4 in.	1 1/4 – 2 1/2 in.	2 1/2 – 3 1/2 in.	Over 3 1/2 in.

Quantifying the ease allowance for a critical anthropometric dimension, however, is not simple because individuals have a various ease preferences. Ashdown and DeLong (1995) studied ease values that related to body measurements in order to determine trends in perceptions and preferences regarding ease values by using sensory and kinesthetic responses. The results indicated that individual subjects could perceive small variations in ease in pants, but the perceived variations and acceptable variations differed by subject. Thus, satisfactory fit is based on more than accurate body measurements, and designers need to consider methods to incorporate individual ease preferences. Ease allowance varies in different pattern construction methods. Gill and Chadwick (2009) investigated the variation in ease allowances incorporated into block pattern construction methods by analyzing five construction methods for women's bodies and sleeve blocks. The results indicated that there was variation in the amounts although the areas (waist and bust) where the ease was required were the same. Therefore, the definition of good fit may differ among individuals and situations. In fit research, however, good fit refers to clothing that provides a neat and smooth appearance and maximum comfort in an intended style of garment.

Good fit can be directly impacted by garment pattern development. Garment pattern development is a process of applying measures of the body accurately to the pattern to develop the intended style of the garment. The pattern is a representation of the three-dimensional body with a minimum amount of ease for body movement and comfort (Armstrong, 2006; Rosen, 2004). Thus, specific knowledge of ease amounts should be considered as well as an understanding of the relationship between the pattern and body to provide better fit.

As ready-to-wear mass-production has increased, the concept of fit has also expanded beyond the relationship between the individual's body and the garment. Current fit issues are associated with the creation of sizing and pattern grading systems to develop garments to fit everyone's body. Sizing is "the dividing of average body or garment measurements artificially into categories to form a range of sizes" (Beazley & Bond, 2003). According to Beazley and Bond (2003), developing size charts for a garment includes five steps: 1) obtaining body measurements, 2) statistically analyzing the measurements, 3) adding ease allowance, 4) formulating the size charts, and 5) fitting the trial garment to test the size charts. Based on the size charts, the master pattern increased or decreased to produce patterns of different sizes; this process is called “grading.”According to Bye (1990, p10), grading is “the process of increasing or decreasing the base size pattern according to a set of body measurements and proportional relationships to develop a range of sizes for production”. Developing a sizing and grading system should involve using anthropometric data representing a target population in order to determine the number and ranges of sizes to accommodate their fit needs (Schofield & LaBat, 2005).

Researchers have tested current sizing and grading systems and their effectiveness associated with fit of garments across a size range. Schofield and LaBat (2005) found that grade rules are not based on anthropometric data, leading to fit problems. Bye, LaBat, McKinney, and Kim (2007) evaluated traditional industry grading practices by testing the fit of graded garments on the body, and found that current grading practices do not provide good fit, particularly for larger sizes. It was found that the current sizing and grading systems need to be improved with alteration to neck, shoulder and armscye.

Figure 1 shows the concept of fit that is influenced by the interaction of a body, garment pattern, and garment at the micro and macro levels. In this garment fit framework, the concept of garment fit at the micro level is composed of the human body, garment pattern, and garment. The relationship between the body measurement and garment pattern development is the key to achieve good visual fit with comfort. The concept of fit expands beyond the individual’s body and pattern at the macro level. The concept of fit becomes more complex with the body sizes and pattern grading. In this framework, measuring the body is the first step and application of these measurements into the pattern development is the second step to develop a perfect fit of garment at the micro and macro level.

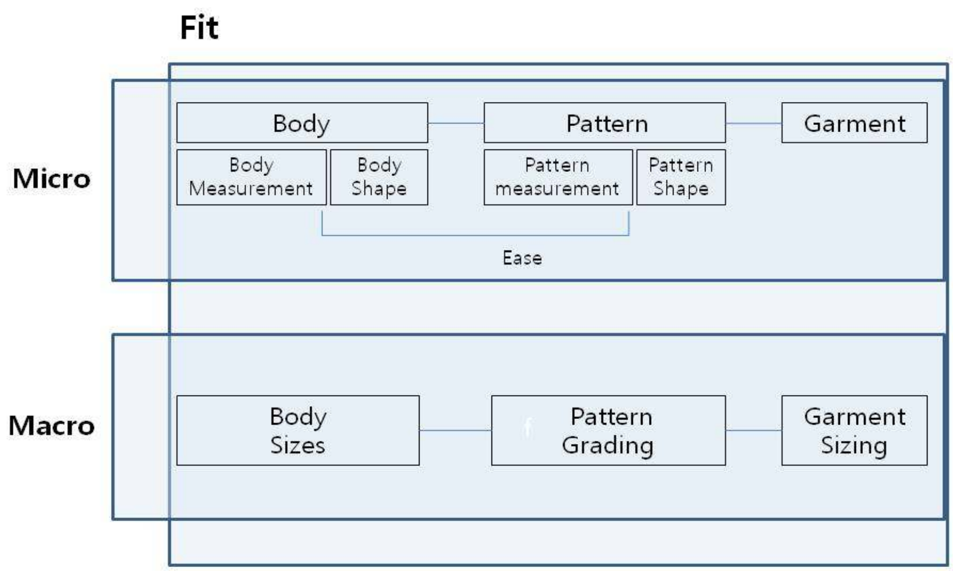


Figure 1. Conceptual Framework for Micro and Macro Levels of Fit

Body Measurement Methods

Linear Method

Traditionally, pattern drafting in the apparel industry involves the process of obtaining the linear measurements over the body surface with a tape measure, and then applying these measurements to draft the pattern based on a mathematical foundation and approximation. The linear measurements are taken between two points on the body. The traditional measuring devices are tape measures, calipers, and anthropometers, and are used to record the essential two-dimensional data related to a three-dimensional form.

There are two types of linear measurements: length and circumference. For example, the length measurement is a point-to-point measurement from the shoulder to the elbow or the shoulder to the wrist bone. This measurement is simple and pure, and is applied to the pattern exactly as taken from the body, without any addition or subtraction. The circumference measurements encircle the body, for example, the bust, waist, hips, or knee. These measurements require added tolerance for ease. Although the ease allowance for circumference is made in all garment design systems, it varies with the type of garment (Hulme, 1954).

For convenience, the linear method has been widely used in studies with large sample sizes. In 1941, O'Brien and Shelton reported the first modern study of women's body measurements using linear measurements. Large-scale studies such as the 1976 U.S. Air Force anthropometry survey and the 1958 U.S. Department of Commerce apparel sizing survey have used linear methods. Goldsberry, Shim and Reich (1996) also used the linear method to describe 6,600 women age 55 and older.

Linear methods, however, are insufficient to describe the three-dimensional nature of the human body (Bye, et al, 2006). The length and circumference of the body do not reflect body shape. For example, even though three human figures have the same chest girth, the shape differs from one figure to another. Therefore, researchers have focused on a scientific investigation into methods of body shape determination.

Somatometry Method

The somatometry approach has been used to describe the graphical human body shape by researchers to develop a method for pattern alterations. Douty (1968) first contributed to the research on body shape relative to the fit of apparel using a research technique called somatometry, which uses photography to capture silhouettes to study body shape. Douty saw the human body as a three-dimensional form made up of a pattern of curves and flat areas. Douty's somatometry method incorporated body posture and proportion into apparel patterns to improve fit in basic garments. Angle measurements were also used to alter patterns by determining shoulder and hip slope on somatographs of subjects.

The somatometry method was important in that it went beyond the simple tape measure for apparel fit and it was a precursor to more sophisticated three-dimensional methods of measuring the human body. Many researchers verified that this method achieved better results of describing the body for improved garment fit. Pouliot (1980) demonstrated that the somatometry method was effective in creating a well-fitting garment pattern by comparing the fit of pants patterns altered by angle measurements to the fit of patterns altered by length and circumference measurements. Shen and Huck

(1992) adopted the somatograph technique to determine body angles and curves. They tested a method of using photographic data, in combination with minimal physical measurements from the body, to empirically test the female garment development proposed by earlier researchers. They were experimental in their approach to translating body measurements into two-dimensional patterns, and they concluded that the somatograph technique showed potential for providing a better fit than those produced by the conventional pattern drafting method of hand-drafted bodices.

Another approach was used by Heisey, Brown, and Johnson (1989) who presented a mathematical framework for analysis of the graphic somatometry method of alteration. They claimed that drafting and alteration methods contain implicit assumptions about the geometric relationships between the two-dimensional shape of a pattern and the three-dimensional form of a completed garment. They noted that the angles of fitting devices in any portion of a garment that can be modeled as part of a cone can be determined from the relationship. The angle of a dart or a seam was determined from angles measured on the silhouette somatographs of the body. Although this approach seems valid in theory, it has not been entirely satisfactory for any area in which the garment must curve in more than one direction (e.g. the side seams of the skirt and trousers and possibly the shoulder area of the bodice).

3D Body Scanning Technology

These early somatometry methods made it possible to represent 3D data of the human body and showed potential for improving the fit of garments, but these experimental studies were limited to testing basic garments. Since the 1990s, 3D body scanning has received greater attention and application in apparel product development. With the development of body scanners, a variety of angles and shapes as well as linear measurements from the data, including length, width, and circumference can now be extracted for use in pattern making. Research has also been conducted to develop advanced 3D methods with the potential to produce optimum patterns and achieve good fit. The visual image from a 3D scanner can be rotated on the computer screen, providing the ability to observe body shape. The data are given in the most complete form of any method and include point, line, surface, shape and volume of the body.

These new technologies are predicted to produce more accurate methods of describing the body than standard linear methods, and are faster and less invasive.

Kang and Kim (2000) proposed automated pattern construction methods by flattening 3D scan data to extract 2D shapes. This method provided a clear explanation of the relationship of the 3D body and the resulting 2D pattern shape. McKinney, Bye, and LaBat (2012) investigated body/pattern relationships by relating body measurements and curves extracted from the body scans to drafted pants blocks. They examined the ease amount to investigate the relationship between body and pattern measurements and to analyze body crotch shape and pattern shape to investigate the relationship between body shape and pattern shape. The results indicated that ease amounts vary in relation to body shape, so it is necessary to understand pattern shaping device locations, amounts, and their relationship to body shape to achieve good fit. Chen, LaBat, and Bye (2010) also used 3D scanning technology to analyze components of body shape including angle data of the shoulder slope, acromion placement, bust prominence, and back curvature. The findings revealed a relationship between body shape and bra fit and Chen concluded that information about body shape has a significant impact on bra fit. Similarly, Hwang Shin and Istook (2007) found that body shape has an influence on garment fit problems. They investigated the fit issues related to pants fit, using body scan data of body dimensions of various demographic dimensions. They revealed that even ethnic groups within the same figure type size category had significant body shape differences and different fit problems. There was a variety of body dimensions in each ethnic group.

Furthermore, the body scanning technology suggests a new way of garment development such as 3D garment design and virtual try-on of a designed garment. From the scan data, a body form can be used as a digital form and this would enable to provide custom design for personal fit garments (Xu, Yu, and Chen, 2002; Lim, 2009).

Body Measurement in Movement

Human movement is a significant factor to body measurement changes. Wakins (1995) required clear descriptions of movement for application to clothing. Kirk and Ibrahim (1966) explored body expansion and contraction by looking at skin stretch.

They suggested that the skin stretches during physical activity and should be considered when evaluating the performance of stretch fabrics for garment design. The results of tests on skin stretching in various body areas such as the buttocks, back, elbow, and knee represented changes of various dynamic body positions and were expressed as a percentage of the skin length in a normal body position. Their study was the first to identify the relationship between the body changes in movement and the fit of a garment. Later, Loten (1989) quantified body measurement changes caused by seven dynamic body postures from a standard position. These changes ranged from 18 cm to 27 cm; the areas where the extreme body measurement changes were found included the shoulder, elbow, waist, and knee joints.

Using a 3D body scanner, Lee and Ashdown (2005) analyzed the changes in upper body surface measurements between the standard anthropometric position and various dynamic positions. Their study found that shoulder length, interscye front and back, and biacromion length were affected the most in dynamic postures. Choi and Ashdown (2011a) also analyzed the changes in lower body surface measurements among the active postures using a 3D scanner and found significant changes in measurements in the active postures from the standard standing scan posture.

As a method of measuring the dynamic body, body surface measurement changes in active postures have been considered when measuring the human body for garment fit. The measurement data was collected in some selected postures for the measurements of maximum increase or decrease. For example, shoulder flexion, scapula protraction, and scapula elevation were selected for upper body measurement changes (Lee & Ashdown, 2005). Choi and Ashdown (2011a) examined the changes in three active postures: 120 degrees knee-bend posture, one-pace posture, and sitting posture with a 90 degrees knee-bend. However, the natural movements in real activities are more complex than controlled postures used for study. Aldrich, Smith and Dong (1997) identified the difference between ergonomic measuring positions and the natural postures in real activities. It was found that serious garment distortion occurs in the upper arm, back, elbow and armhole areas when extended natural body postures are performed, and garment restrictions on the body affect comfort significantly.

Measuring body movement and posture has been recently studied with a motion capture system (Mattman & Tröster, 2005; Mattmann & Tröster, 2006; Mattmann, Clemens, & Tröster, 2008). A number of studies within the field of human body motion using a motion capture system have grown significantly over the past two decades. Human motion capture studies have focused on automatic initialization, tracking, pose estimation, and movement recognition (Moeslund, Hilton, & Kruger 2006). Initialization of shape, appearance, and pose can be addressed from manually identified joint locations. Motion-based, appearance-based, and shape-based segmentation can be detected, and the configuration of the underlying kinematic or skeletal articulation structure of a person can be estimated. Few studies on human motion capture and analysis have been conducted in the field of apparel studies. The motion capture system allowed measurers to measure the body expansion or contraction over time during activities. Mattan, et al (2008) verified the feasibility of calculating body posture with a motion capture system, which used on-body sensors integrated into a tight-fitting garment. They investigated the measurements of the back of the body in different sitting postures by the elongations of the clothing. During this study, a total of 90 markers were arranged in a 5 cm grid. By analyzing the distance between the markers, the elongation of the clothing could be measured. The results of this study showed that the method was suitable for measuring the movement and posture by knowing the elongations of clothing. Elongations were up to 11 % on the sides and up to 17% in the lower back in the vertical direction while bending the upper part of the body. However, the study was limited to one subject. The results of their study suggested the feasibility of using the motion capture system to measure dynamic body changes.

Landmark

Clear, consistent body landmarks are critical to secure accurate measurements for basic pattern development (Bye, et al, 2006). Anatomical points are typically used as landmarks for garment pattern development. According to Yu (2004), there are 19 key landmarks corresponding to the anatomical points. The landmarks include the neck joint, high point shoulder, short shoulder, long shoulder, neck joint, neckline, center front neck, 7th cervical, center back neck, elbow, wrist, crotch, bust level, waist level, upper hip level, hip level, knee level, ankle level, top of head and floor (see Figure 2).

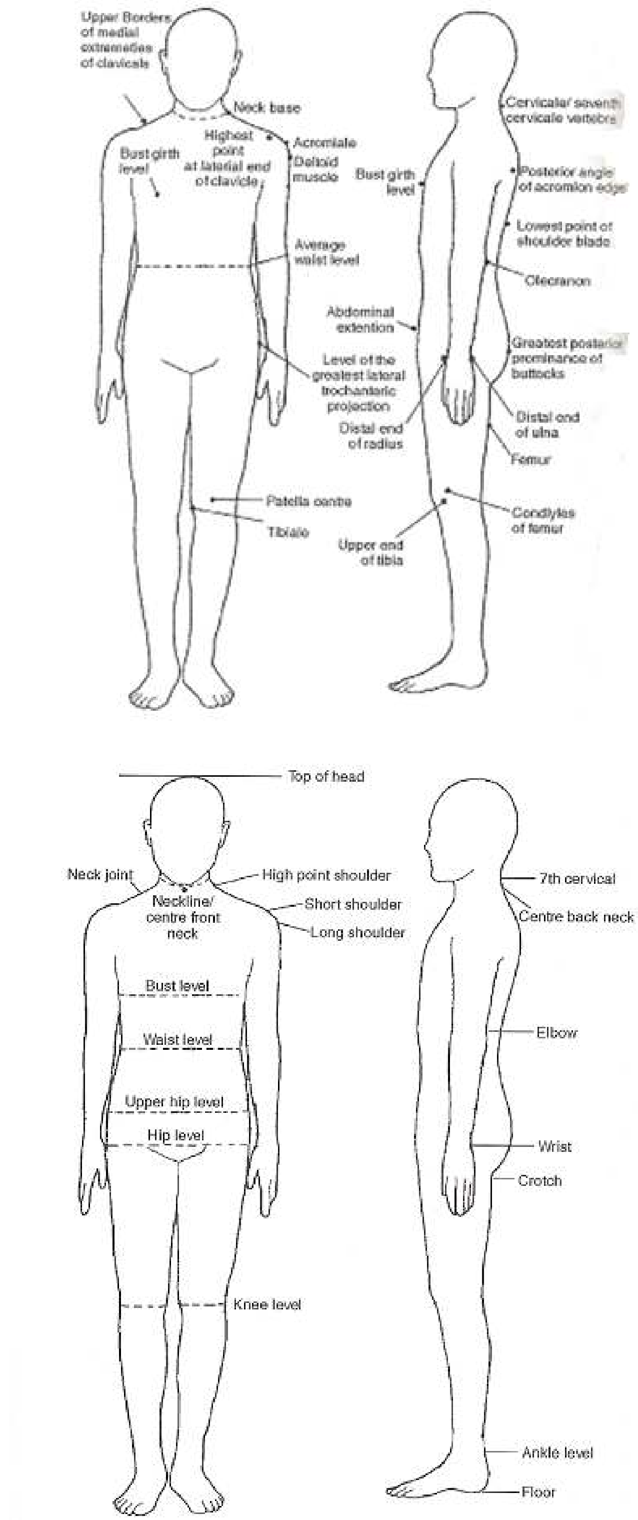


Figure 2. Critical Anatomical Points and Key body Landmarks by Yu (2004)

For the purpose of pattern development based on body shape, Efrat (1982) suggested using the locations of 26 crucial shaping points from the female bodice pattern construction method using the conical principle. These points were considered to reflect the three-dimensional nature of the human body in a two-dimensional pattern. The points included the apex of the bust, the apex of the shoulder blade, and three or four points on the waist, side, neck, armcye, and shoulder (see Figure 3).

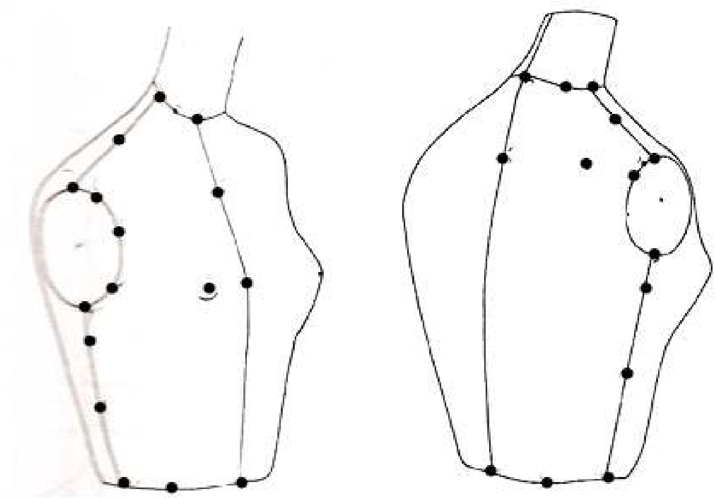


Figure 3. Location of the Crucial Shaping Points by Efrat (1982)

Schofield and LaBat (2005) suggested seven body landmarks related to pattern cardinal points. Cardinal points are the points on a pattern where the grade rules are applied to increase or decrease the pattern. The seven body landmarks include suprasternale (center front of pattern), trapezius point (side neck), acromion (shoulder point), bust point (bust dart), waist level, cervical (center back neck), and mid-shoulder (shoulder dart leg). Using these landmarks, a total of 21 measurements were recommended to be included in size charts: 9 linear and 12 girth measurements. Linear measurements are height, waist length from center front, cervical to natural waist, cervical back to natural waist, cervical height, outside leg length, inside leg length, arm length, and shoulder width. The girth measurements are neck girth at midway level, neck girth at neck base, bust, natural waist, intended/artificial waist, hip 4 (hip measured at 4 inch below the natural waist), hip 6 (hip measured at 6 inch below the natural waist), thigh, ankle, knee, upper arm, and wrist. For the landmarks in most pattern development, obvious places such as bony protrusions and bust points and the center points of the body such as cervical are considered key points.

Garment Fit and Body Movement

Ease and Movement

Most research on ease allowance has been based on body movement analysis and body measurement change analysis. Body movement analysis is an effective method for the study of ease. The best ways to precisely identify the areas in which ease is needed is to look at the elongation and contraction of a specific body area and relate it to the elongation and contraction of clothing placed over it. Huck, Maganga, and Kim (1997) found that clothing ease can be determined by using body movement analysis. In their study, changes in total crotch length or back length for different active postures were analyzed and the needed crotch ease in a one–piece protective garment was determined. To determine the ease amounts, they needed to analyze both body movement and body measurement changes at the same time. In particular, the body measurement change for a specific body movement was needed. Ease is directly related to body surface change through movement. In Choi and Ashdown's (2002) study, ease was incorporated into the pattern of work clothing for female pear farmers, so garments were designed according to the effects of body movements on body measurements. Choi and Ashdown (2011b) also identified pants with a ideal ease amounts, using the measurements of lower body surface changes. Waist girth in the sitting posture increased 8% compared to a standing posture and the hip girth measurement increased 7%.

Joint movement is considered the most important factor in body movement and measurement change analysis. When the joints move, it allows the skeleton to work with muscle and body movements. When there is body movement, positions of different joints change significantly, and body skin surfaces around the joints are extended and contracted. Thus, body skin surfaces change which informs body measurement changes. Wang, Mok, Li, and Kwok (2009) found that there is an interaction between joint movement, body measurements and clothing ease. Their study explored the changes in human body measurements with different joint movements. Thus, they measured the human body in 19 active postures including joint movements of the elbows, shoulders, waist, hips and knees. In joint movements, lengths and circumferences of the body around the joint changed remarkably. Eighteen measurements were determined to be the principal body measurements in active postures: (1) circumference above the waistline: elbow, bust, forearm, and wrist girth; (2) width: horizontal shoulder and back width; (3) length above the waistline: arm length, under armhole point to waist length and the 7th-cervical to waist length; (4) circumference below and with the waistline: knee, mid thigh, calf, ankle, hip, and waist girth; (5) length below and with the waistline: crotch depth, front leg, and outside leg length. The maximum increase (8.4cm) was found in the under armhole point to the waist and the maximum decrease (-15.75cm) was found at the horizontal shoulder width. They concluded that the back width, top side length, and hip girth as well as knee girth are crucial parts of the human body for clothing ease.

There is little literature to support the ease amount in relation to the location of the body in pattern development methods. Gioello and Berke (1979) suggested the amounts of movement/comfort ease to be added to the body measurements to assure fit of the garment, although they did not mention how ease values were determined. The amounts of ease vary with the location of the body (see Table 2).

Table 2. Movement/Comfort Ease Suggested by Gioello and Berke (1979)

Location/Area of Body	Movement Ease/Comfort Ease
Neck	
Total Girth	¼ - ½ in.
Chest (At armcye)	
Total Girth	½ in.
Bust	
Total Girth	2 ½ in.
Front Width	1 ¼ in.
Back Width	1 ½ in.
Waist	
Total Girth	1 in.
Front Width	⅜ - ½ in.
Back Width	½ - ⅝ in.

Shoulder Blade (from armcye to armcye) Width Across	½ -1 in.
Shoulder Length Neck to Armscye	N
Neck to Waist Front Length Back Length	 ½ - 1 in. ½ - 1 in.
Shoulder to Waist Front Length Back Length	 ½ in. ½ in.
Shoulder to Crotch (Vertical Trunk)	1-2 in.

Ease and Sizing

In most studies on sizing garments, ease amounts have not been considered. Schofield and LaBat (2005) provided insight into the relationship between the pattern and anthropometric data in sizing and grading of clothing. However, ease was not discussed. Presumably, the same amount of ease is applied across the size range. In another pattern grading research study, ease amounts were two inches at the bust and the hip, and one inch at the waist, and were consistent across the size range (Bye, LaBat, McKinney and Kim, 2007).

Ease may vary with body sizes. Gordon (1986) suggested that sizing garments should be based on size-dependent ease amounts. Petrova and Ashdown (2008) examined the ease in pants for size and shape dependences. Ease amounts were calculated by the difference between body and garment measurements as a percentage of the corresponding body measurements. This was reported as “garment-body percent difference”. Using 3D body scanning technology, the gap between the scan of the body and garment were measured. The results indicated that the percent ease difference decreased with increasing size, but a dependence on shape was not found. No significance changes were found for the percent differences except for the size dependence of the hip circumference. The concept of ease used in their study is based on the visual fit; thus, the wearers’ perception of ease was not considered. Research on ease across sizes is still limited although garment ease is considered an important factor to comfort and fit.

Summary: Literature Review

Garment fit can be improved by better understanding of the interaction of human body, pattern, and garment. The body measurement method is critical in achieving good fit of a garment. Researchers have developed new methods to measure the body more accurately for producing better fit of a garment with the advent of apparel technology, such as somatometry, 3D body scanning, motion capture system, and CAD applications. The next frontier of body measurement methods might be measuring the body in motion and its application to garment development. Human movement is a significant factor that impacts body measurement changes, which is related to wearing ease amounts. Previous research focused on the changes in body surface measurements between the standard anthropometric position and various dynamic positions. Using a motion capture system, more natural continuous motion during real activity could be considered, but few studies have focused on the body measurement changes during natural movement and the difference in body measurement changes across body sizes.

CHAPTER THREE: METHOD

The research method is discussed in the following order: 1) research design, 2) selection of participants, 3) limitations, 4) data collection, and 5) data analysis. The methods for this study were developed to examine body measurements using a motion capture system.

Research Design

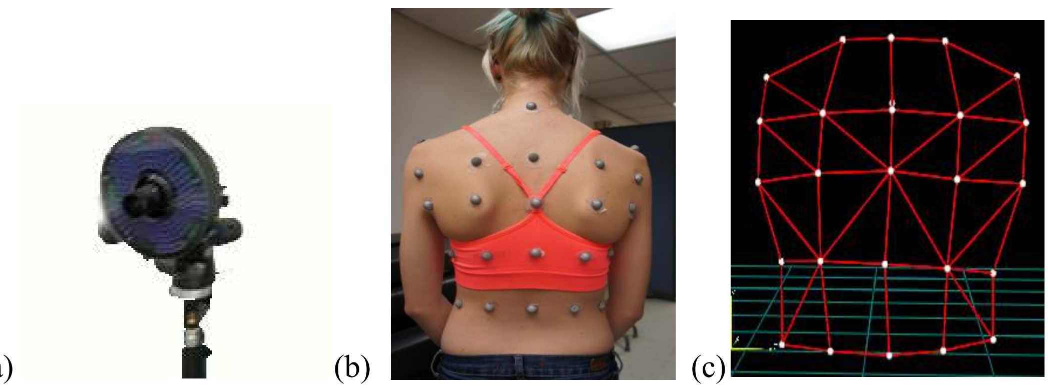
Research Purpose

The purpose of the research was to explore the research method to examine body measurements using the motion capture system. This study tested the accuracy and reliability of a motion capture system in measuring a human body compared to the 3D body scanner. The second purpose of this study was to investigate the body measurement changes in motion and to examine the measurement changes in motion across body sizes.

Selection of Motion Capture System

The BTS SMART - e system, which is an optical motion tracking system, was selected to measure the body surface change in motion because it can simultaneously measure and record the body measurements and provide accurate numerical data for analysis. The BTS SMART system consists of three software models: the SMART-Capture, the SMART-Tracker, and the SMART-Analyzer. The SMART-Capture captures motions and force data using six cameras that view various reflective markers on the moving object (see Figure 4). Each camera captures the x, y, and z position of each marker over time; data is saved every .017 sec. The markers used were hemispheres with a retro-reflective surface. The size of the marker used for this study was 15mm in diameter (see Figure 5). The SMART-Tracker converts the 2D data from the SMART-Tracker to 3D, and the 3D data can be viewed from any orientation. The advantage of the motion capture system is that it can provide measurement change over time for a specific motion, rather than a measurement at a certain stage of motion.

Figure 4. BTS SMART System



(a) (b) (c)
Figure 5. (a) Infrared Camera, (b) Reflective Marker on Subject, (c) Recorded Markers in the Motion Capture System

Selection of Motion

This study focused on the upper body because it was found that serious garment distortion occurs in the upper arm, back, elbow and armhole areas when extended body postures are performed (Aldrich, Smith and Dong, 1997).

The upper body movements in relation to the shoulder girdle were selected for a motion test for this study because the shoulder is the most mobile of all the joints in the human body (Kapandji, 2007). The shoulder girdle supports the two arms, and provides attachments for several muscles involved in movements of the head. Good mobility and coordination of the joints and muscles of the shoulder are essential for many of our activities. The joints of the shoulder girdle are presented in Figure 6.

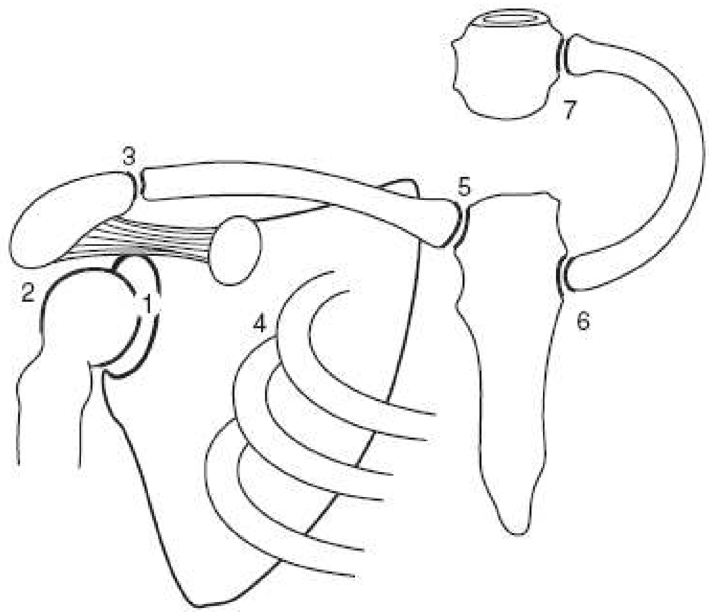


Figure 6. Joints of Shoulder Girdle: (1) Glenohumeral, (2) Suprahumeral, (3) Acromioclavicular, (4) Scapulocostal, (5) Sternoclavicular, (6) Stemocostal, and (7) Costovertebral (Interactive Physiology 9-System Suite, 2006)

The shoulder has three degrees of freedom with three main axes, permitting the movement of lateral or medial rotation. Movements at the shoulder involve three joints: the glenohumeral joint (between the scapula and the humerus), the stenoclavicular joint (between the sternum and the clavicle), and the acromioclavicular joint (between the scapula and the clavicle). Thus, the motion tests for this study were associated with the movements of the glenohumeral joint, and the sternoclavicular and acromioclavicular joints, with the goal of investigating a wide range of motions that affect body measurements. The selected motions for this study were the arm rotation and golf swing.

Arm rotation. Arm rotation was selected because the positions of the upper arm and lower arm play an important role in relation to garment performance and functional comfort level (Aldrich, Smith and Dong, 1997). This motion test included combined anterior and lateral movements.

Figure 7 shows the sequence of the arm rotation motion. The starting position was the natural standing pose; the upper limbs hung down vertically alongside the trunk. Both arms were raised in front of the body in a sagittal plane and continued until the arms were held straight overhead. This movement raised both arms 180 degrees from the starting position. This flexion is the most common shoulder movement (Calais-Germain, 1996). Then, both arm moved laterally away from the body in a frontal plane until both arms hung at the side of the body again. The range of motion (ROM) was almost 180 degrees. This adduction movement is common in specific physical disciplines or exercises (Calais-Germain, 1996).

Figure 7. Arm rotation

Golf swing. The golf swing was selected because golf is one of the most popular sports that requires a sequence of motions related to the shoulder joints. This motion was selected for testing the motion capture system's ability to measure the natural moving body in sports. According to the National Golf Foundation (2010), 27.1 million Americans are golf participants. This includes anyone ages 5 and above who either has played a round of golf or has visited a golf practice facility. More than 45 % of golfers (11.9 million) are between the ages of 18 and 39. There are 4.7 million female golfers, which is 19% of all golfers. The basic golf swing motion included the initiation, backswing (Takeaway and Top of the backswing), downswing, impact and follow-through (see Figure 8).

The five phases of the golf swing are as follows (Roberts, 2005):

1. Initiation—getting into position for starting the golf swing

Shoulders and arms are relaxed, in front of the body, and spine is in a relaxed neutral position. Arms are in front of the body with tension in the forearms, wrists, and hands. Trunk and spine extensors, or back muscles, are stabilized to hold the address position

2. Backswing

a. Takeaway- swinging slowly away from the ball

b. Top of the back swing- moving the club head from the address position to the top of the arc

Golfer rotates the trunk and lifts the club with the upper extremities. The head rotates toward the left. The shoulder muscles are active as the club moves away from the ball. The shoulder girdle remains active, including the rotator cuff, as the golfer lifts the club. Counter-rotation occurs at the shoulders, midback, and lumbar spine toward the right (approximately 90 degrees). Rotation of the lower extremities occurs at approximately 45 degrees.

3. Downswing—moving the club head from the top of the arc toward impact with the ball

The direction of swing changes from right to left. The highest forces of side bending, shear, and rotation occur at the neck and low back during this phase.

4. Impact- The phase of the golf swing where ball contact occurs.

The greatest muscle activity and tension is produced as the muscles contract to bring the club to the ball. The head and neck experience a side-bending motion toward the right, combined with a forward bend. Shoulders are brought back to a square position. The shoulder girdle, including the rotator cuff, is active. Other muscles that connect the shoulder blade to the rib cage, and the pectoral or chest muscles are actively accelerating the arms. The mid neck muscles, including the lower trapezius, act to stabilize the shoulder blade. The trunk muscles produce a side-bending motion toward the right combined with a rotational motion toward the left.

5. Follow-through—moving the club past impact to the follow-through position

Deceleration of the body as the golf club is moved to a position over the left shoulder. The shoulders move in reverse motion of the backswing, with the club finishing overhead. The pelvis and trunk have turned toward the target. The left hip rotates, straightens, and moves toward the midline of the body, while the right hip moves to a neutral position facing the target. The left knee straightens, while the right knee remains bent with balance on the toes. The spine maintains a neutral or slightly side-bent position toward the right.

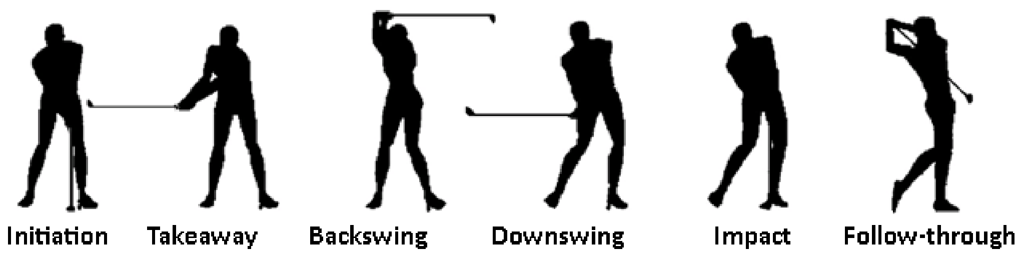


Figure 8. Golf Swing

Selection of Measurements

Measurements for this study were selected based on their application to pattern development. Thus, the measurements were determined from the bodice back pattern. Measurements between two points were used; they were all linear surface lengths.

Landmarks act as stable points, and were defined for each measurement (Figure 9). For the back of the upper torso, the landmarks include (1) the cervical (the prominent bone at the top of the spine), (2) the trapezius point (shoulder, side neck), (3) the acromion (the outer tip of the shoulder), (4) the axilla (the highest points of the right and left axillary folds on the back), (5) waist (the narrowest level of the torso) and (6) the mid spine (Gordon, 1986). The cervical is related to the center of the back of the neck of a garment and the mid-spine is used to locate measurements on the back.

Five horizontal and three vertical measurements that are related to pattern development for the upper body were selected (Armstrong, 2006). Additionally, two diagonal measurements were selected. The two diagonal lines can provide three-dimensional changes on the back of the body during the motion. Horizontal measurements included across the shoulder width (S), back width (B), the back arc at the armpit level (BA), the lower back arc between armpit and waist (LB), and the waist arc (W). Vertical measurements included a left side length (LS), center back length (CB) and a right side length (RS). Diagonal measurements included a right diagonal (RD), which was from the right shoulder tip to the left side waist and the left diagonal (LD), which was from the left shoulder tip to the right side waist. The measurements are as follows:

Horizontal measurements

1. Shoulder width (S) – shoulder tip (acromion) to the center of the neck (cervical)
2. Back width (B) – center of the back to the middle point between the shoulder tip and the armpit
3. Back arc at Armpit level (BA) – center of the back to the armpit
4. Lower back arc (LB) – center of the back to the middle point between the armpit and waist level
5. Waist arc (W)– center of the waist to the side waist

Vertical measurements

6. Left side length (LS) - left armpit at the side to the side waist
7. Center back length (CB) - center of the neck (cervical) to the waist
8. Right side length (RS) - right armpit at the side to the side waist

Diagonal measurements

9. Right diagonal (RD) – right shoulder tip to the left side waist
10. Left diagonal (LD) – left shoulder tip to the right side waist

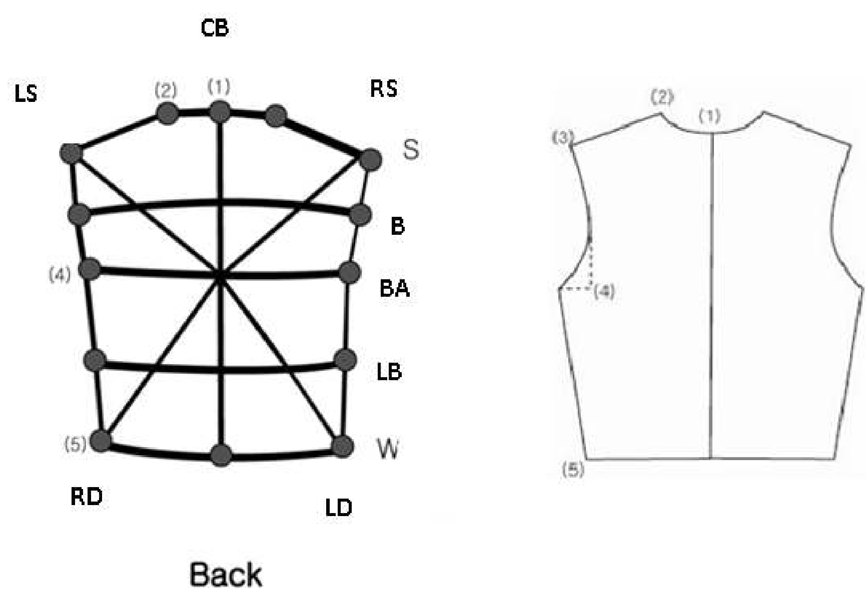


Figure 9. Relationship of Body Landmarks to Bodice Back Pattern (1) Cervical, (2) Trapezius (3) Acromion, (4) Axilla, (5) Waist

Research Questions

The specific research questions are:

1. Is the motion capture system a reliable method to measure the human body?
    a. Are the repeated measurements extracted from the motion capture system reliable?
    b. Is there any variation between the body measurements extracted from the body scanner and the motion capture system?
2. Is there any variation in the upper body measurements during motion?
    a. How do the ten selected upper measurements change during the arm rotation?
    b. What are the maximum increases and decreases of the ten selected upper measurements during the arm rotation?
    c. How do the ten selected upper measurements change during the golf swing?
    d. What are the maximum increases and decreases of the ten selected upper measurements during the golf swing?
3. Is there any variation in measurement changes among participants who have different levels of expertise in golf?
4. Is there any difference in measurement changes among participants with different body sizes?

Selection of Participants

Participants were recruited through posters and snowball sampling. The posters were placed throughout the Twin Cities campus at the University of Minnesota. Participation was restricted to women between 18-39 years of age because more than 45 % of golfers are between the ages of 18 and 39 (National Golf Foundation, 2011). The voluntary participants were paid a small compensation. The participants for the golf motion test were golfers who played golf at least once a year, so that they had experience with the golf swing motion. Expert golfers for this study were expected to have played more than 5 years and participated on a golf team. They were recruited from the women's golf team or the Department of Kinesiology at the University of Minnesota.

Potential participants were screened to find individuals whose bust and waist circumference measurements were between size 2 and size 20 as specified in the ASTM D5585-95R01 (2001), the standard table of body measurements for adult female Misses figure types, sizes 2-20. A Human Solutions VITUS/SMART 3D scanner in the Human Dimensioning© Lab (HDL) was used to scan the participants to obtain body measurements. Institutional Review Board approval was acquired before proceeding with the study. Final IRB approval was received on August 15, 2011 (IRB study number: 1108P02981).

Limitations

The participants were limited in age range and were all women. The participants' body shapes and postures were not considered. Further research is needed to consider body shape and posture, and include male participants.

This study was limited to the upper body measurement changes, focusing on the back of the body. The tests were limited to two motions that were related to upper body movement. Further research needs to examine the circumferences and lengths of the upper body and the lower body.

Data Collection Procedure

The data collection procedure included five steps: preparation of the motion capture system, subject registration, the marker placement process, the scanning process, and the motion capturing process.

Preparation of the Motion Capture System

Preparing the working area and camera. The motion was limited to the upper body; thus, the dimension of the working area was 150cmX150cm. The six cameras were placed around the working area and the system was turned on in order to aim the cameras precisely and focus the lens at the center of the working area. The researcher aimed each camera by adjusting the screw of the tripod and the camera head and eventually by moving the tripod if necessary. Finally, the six cameras were placed 75cm apart from one another surrounding the working area. The same working area and camera position were used for both motion tests.

Calibration. After positioning the six cameras to aim at the working area, calibration was necessary using the two hinged axes and wand provided with the system. Before each motion capturing, a new calibration file was created to store the calibration parameters in Smart Capture software. The two hinged axes were spread out to make a 90 degree angle L shape and the wand was inserted in the origin of the two hinged axes. This tool was placed on a table at the height of 100 cm where the participant will be standing and captured for four seconds; the two hinged axes represented the X and Z axes, and the wand represented the Y axis (see Figure 10). Then, the researcher disassembled the two hinged axes and the wand, and captured the movement of the wand, moving it up and down several times along each axis, by sweeping the working area with the wand. During this process, all cameras must view the wand for a reasonable number of frames, about 90 seconds. When the calibration sequences were acquired, the calibration wizard started automatically. Unless there was an error message, the calibration processing ended correctly. This process was done every time the camera head or the position of the camera changed and before the participant's visit.

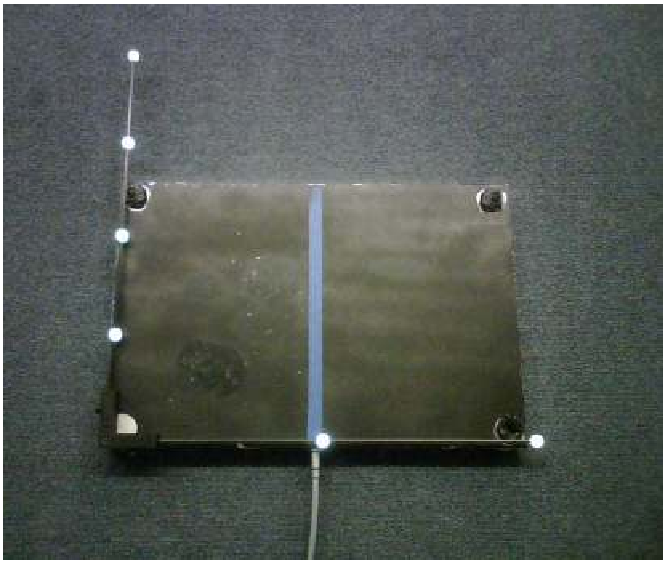


Figure 10. X, Y, and Z Axis for Calibration

Pilot testing. Before initiating the capturing process, a pilot test was conducted to determine where the markers needed to be attached and how many markers were necessary. The pilot process allowed for the development of testing, the refinement of methods and the application of equipment. It was necessary to test and refine the marker positioning during the pilot. Attaching the markers was fundamental to measurement placement. The pilot subject was not used in the actual test.

The arm rotation and golf swing were evaluated as motion tests. The markers were attached 5cm and 10 cm distance from each other on the selected measurements (see Figure 11). If necessary, the position of the cameras was adjusted and a new calibration was done each time.

Figure 11. Markers 5 cm Distance from Each Other

This study concentrated on the back of the body while the subject performed the motion tests. Based on this pilot test, the following were identified:

- To capture the markers, they should be attached on the body 10cm distance from each other. It was found that 5 cm distance was too close to capture the position of the markers correctly during the motion.
- A large influence of the arms on the back of the upper body was observed. When the markers were covered by other body parts, the information of the occluded marker location was lost. Markers should not be occluded while capturing the motion.
- The motion needed to be slow enough to let the camera capture the position of the markers. It was found that the arm rotation motion should be performed within the 1500 time frame, which was about 20 sec. The golf swing motion should be performed within the 2400 time frame, which was about 35 sec. The golf swing motions should be slowed down.
- The researcher decided to measure subjects three times due to intra-measurement variation and to take an average of three repeated measures. There was a need to guide achievement of motion and to control motion during the test. Undertaking this analysis indicates the difficulties of repeat measurements (see Figure 12); however, with an

awareness of this, care can be taken during the tests to reduce error, especially for measurements showing high variability.

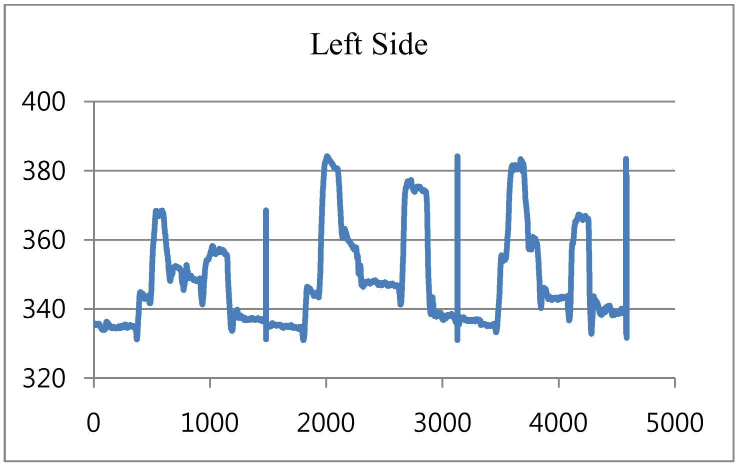


Figure 12. Example of Measurement Changes During the Three Repeated Motions

Subject Registration

The research process took place in the Human Dimensioning Lab and Wearable Technology Lab at the Wearable Product Design Center at the University of Minnesota, where the body scanner and optical motion tracking system is located. Once participants were selected through the screening process, they were asked to schedule a 30-minute appointment with the researcher and to wear non-restrictive sports pants. When the participants came to the Human Dimensioning Lab, they were given a consent form and participant information form to complete before data collection begins. After completing the forms, the participants were given bras and a robe for this study and asked to change into the bras in the dressing room. The bra was made of 94 % nylon, 6 % lycra, was wire-free and had adjustable straps (see Figure 13).

Figure 13. Bra for test

The Marker Placement Process

Markers were needed for the optical motion tracking system and were placed at locations on the body corresponding to the selected measurements. Fifteen mm diameter markers were attached on the participant's skin with double-sided sticky tape.

The markers were placed at the two end-points of each measurement. Anatomical landmarks that are related to pattern development helped to establish the accurate placement of the markers. The markers were attached on the body where the anatomical landmarks were obvious such as the cervical and the acromion. The marker attachment process was as follows:

A total of 11 markers were placed on each end-point of the selected measurements on the right side of the back. First, the markers were attached on the center of the back of the neck (cervical) and the right tip of the shoulder (acromion). Then, a marker was placed on the right side of the neck (trapezius point). Second, markers were placed on the armpit (axilla), and on the center of the back at the armpit level. Third, a marker was attached at the middle point between the right shoulder tip and the armpit (B). Next, at the waist level, markers were attached on the center of the back and at the side. In this study, the side was perpendicular to the armpit point; it did not represent the side of the garment pattern. Lastly, markers were attached at the middle point of the right armpit and on the side at the waist, and on the center at this level (LB). Finally, one more row of sensors was placed between the two end-points on the right side. Similarly, markers were attached on the left side of the back. Each of the markers was 7-10 cm apart to capture the curve of the body; thus, a total of 25 markers were placed on the back of the body (see Figure 14). The small bumps on the selected measurements were the physical raised landmarks that were placed on each participant prior to scanning.

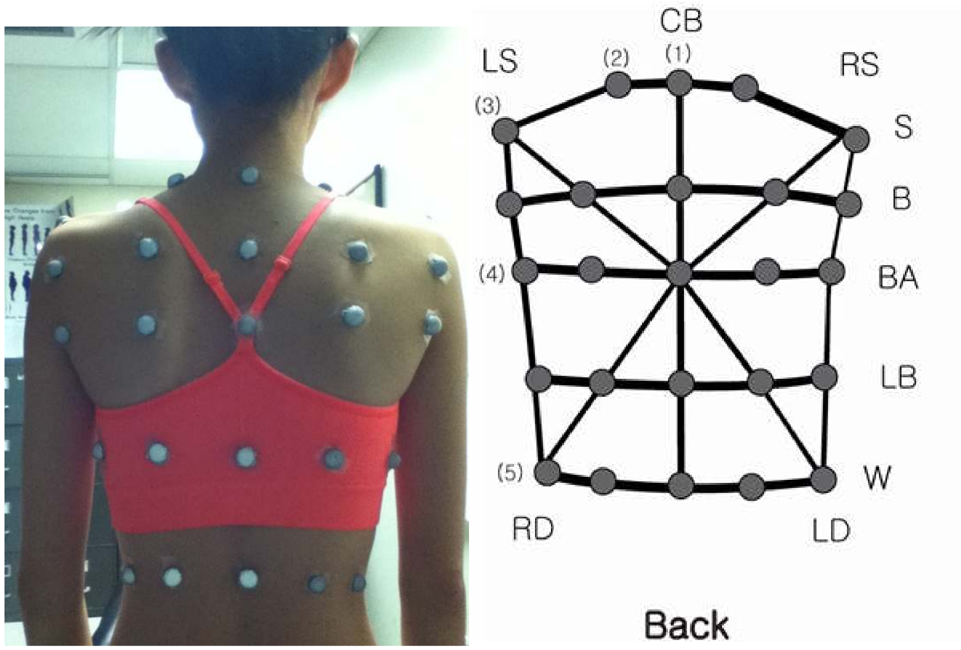


Figure 14. Attached Markers on the Body

The Scanning Process

Once the markers were attached, the participants were asked to stand in the body scanner with feet on the position markings of the platform. The participants were asked to stand in a natural and relaxed posture; they stood still, looked forward, and breathed normally during the scanning. The basic standing posture was described as: the participants were asked to stand upright but natural, relaxed and looking straight ahead, with feet together and arms hanging relaxed at the sides (Aldrich, Smith, & Dong, 1997). When the scan was finished, the data was checked for quality and, if needed, the participants were rescanned. After scanning, the participants were asked to wear a robe and move to the Wearable Technology Lab for motion capturing.

The Motion Capturing Process

Before starting, the participant did stretching exercises (5 minutes) to warm up the muscles. A reference video of motion required for this study was shown to the participant, and the participant performed the motion several times with the researcher's guidance.

The participant stood in the optical motion tracking space with six cameras surrounding her. The participant was asked to stand in a natural and relaxed posture, which is the same posture as in the body scanning process. The starting point was the basic standing posture, in order to compare data of the maximum increases and maximum decreases of the body in motion. When the participant was ready, she was asked to perform the selected movements. The participants were asked to perform the arm rotation or golf swing, and repeat the motion three times.

Data Analysis Procedure

The quantitative data were collected from the body scanner and motion capture system. In order to answer the research questions, the quantitative data from the body scanner and motion capture system were analyzed using descriptive statistics, a paired t-test, and an independent t-test. The data were analyzed using the Statistical Package for Social Studies.

In order to answer research question 1, the positions of the participants' markers were recorded three times in the standing posture, using the motion capture system to calculate the variation among the three repeated measures. Intraclass correlation (ICC) was used to measure inter –rater reliability for the three measures. In order to compare the measurements from the motion capture system to the 3D manual measures on the 3D body scanner, descriptive statistics for the measurement from both tools in the standing posture were analyzed. ScanWorX^{TM} incorporated in the software package of the body scanner was used to measure the width and length of the back. The motion capture system recorded the X, Y, and Z position of the markers on the body within the established time frame. Measurement data were transferred from the Motion Tracker to a text file, and the text file was opened in an Excel spreadsheet. The researcher calculated the distance between the markers; thus, a total of 10 measurements in the standing posture were calculated. The measurement from the motion capture was the mean value of the three trials. A paired t-test was conducted to determine whether there was a variation in measurements between data from the body scanner and the motion capture system.

In order to answer research question 2, a total of 10 measurement changes during the arm rotation and golf swing tests were analyzed using a graph format. The measurements were calculated by the distance between two markers. The distances between two markers on the selected measurements were totaled for the final measurement. Using descriptive statistics, the maximum and minimum values of each measurement for the arm rotation and golf swing were obtained for each participant. Analysis of individual body measurement changes during the motion tests were undertaken prior to the mean changes. Measurement changes were established by the subtraction of the static dimensions from the maximum increases or maximum decreases. These values were the mean values of the three trials. A high level of descriptive analysis indicated the levels of change as well as the motion and position of the measurements. In order to answer research question 3, an independent t-test was conducted to determine whether there was a difference in measurement changes between the novice and expert golfers.

In order to answer research question 4, the garment size for each participant was categorized as Small (size 2-6), Medium (size 8-10), Large (12-14), and XLarge (size 16-20). Beazley (1999) stated "A size chart is the artificial dividing of a range of measurements" (p.67). The bust circumference was used as the primary sizing interval for size designation. Using descriptive statistics, the mean values of body measurement changes of each group were compared to determine any variation in measurements among participants with different body sizes.

Summary: Method

The exploratory research was developed based on the framework for micro and macro levels of fit. The methods for this study were developed to examine body measurements using a motion capture system. The upper body movements in relation to the shoulder girdle were selected for a motion test for this study. The selected motions for this study were the arm rotation and golf swing. Measurements for this study were selected based on their application to pattern development. Before the participants' visit, the cameras of the motion capture system were set up and calibrated in the working area. Markers were needed for the optical motion tracking system and were placed at locations on the participants' body corresponding to the selected measurements. Once the markers were attached, the participants were scanned in a natural and relaxed posture using the body scanner, and then their movements were recorded three times using a motion capture system.

The mean value of the three trials in the standing posture from the motion capture was used to compare to the measurements from the 3D body scanner. The mean value of the maximum increase and maximum decrease of the three trials in the ten selected measurements during the motion test was used to examine the body measurement changes. The quantitative data from the body scanner and motion capture system were analyzed using descriptive statistics, a paired t-test, and an independent t-test.

CHAPTER FOUR: RESULTS

This chapter presents the results from the quantitative data analysis. The chapter is divided into three sections. The first section presents the body measurements of the participants. In the second section, the reliability of the motion capture system was evaluated. The inter-rater reliability of the three repeated measures from the motion capture system was evaluated, and the measurements from the body scanner were compared with the data from the motion capture system. The third section presents the measurement changes in the two test motions: the arm rotation and the golf swing.

Participants' Information

A total of the 25 women participated in this study. All of them participated in the golf swing test; six were the golf team members and 19 were novices. Of the 25 participants, 19 participated in the arm rotation test. The bust circumference, waist circumference, shoulder width (S), back width (B), back arc at the armpit (BA), lower back arc (LB), waist arc (W), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) of 25 participants were measured using the 3D body scanner (see Table 3). The bust circumference ranged from 77.7cm to 122.1cm, and the average is 92.67cm. The waist circumference ranged from 62.2cm to 109.7cm and the average was 76. 46cm. All participants were right-handed.

Table 3. Maximum, Minimum, Mean Value of Participants' Measurements

	N	Min	Max	Mean	SD
Bust circumference	25	77.70	122.10	92.67	10.04
Waist circumference	25	62.20	109.70	76.46	10.62
Shoulder width (S)	25	35.00	44.30	40.71	2.00
Back width (B)	25	30.50	42.90	37.44	2.43
Back arc at the armpit (BA)	25	31.00	40.20	35.69	2.34
Lower back arc (LB)	25	26.60	37.70	31.40	2.72
Waist (W)	25	22.00	34.20	27.84	2.84
Left side length (LS)	25	30.80	38.00	34.50	1.93
Center back length (CB)	25	32.60	39.20	35.90	1.96
Right side length (RS)	25	30.00	37.50	34.16	1.93

Right diagonal (RD)	25	45.90	54.90	51.10	2.57
Left diagonal (LD)	25	47.00	55.80	51.25	2.30

Body measurements for the 25 participants for the arm rotation and/or golf swing test are shown in Table 4. A total of 25 participants were sorted into size small, medium, large, and extra large using the bust circumference. Six participants were size small ranging from 77.7cm to 86.4cm. Seven participants were size medium ranging from 86.5 cm to 91.4 cm. Eight participants were size large ranging from 91.5 cm to 99.1 cm. Four participants were size extra large ranging from 99.2 cm to 122 cm. Of the 25 participants for the golf swing motion test, 19 participants (N1-N19) were novice golfers and 6 participants (P1-P6) were expert golfers. (see Table 4)

Of the 19 participants for the arm rotation (A1-A19), five were size small, five were size medium, seven were size large, and two were size extra large.

Table 4. Participants' body measurements for arm rotation and golf swing motion test

Arm rotation	Golf swing	size	Bust	Waist	S	B	BA	LB	W	LS	CB	RS	RD	LD
A1	N1	S	77.7	64.3	39.0	34.4	31.0	28.0	25.0	32.5	34.0	31.9	48.0	48.0
A2	N2	S	80.0	62.2	37.0	34.0	32.3	27.0	22.0	33.0	33.1	33.7	45.9	47.5
A3	N3	S	80.1	67.5	42.2	36.4	34.2	29.3	25.9	34.6	37.0	34.8	51.6	49.2
	P1	S	80.1	69	40.09	37.85	35.18	29.65	24.67	32.6	33.7	33.15	48.2	49.9
A4	N4	S	84.5	65.3	40.3	35.8	33.7	26.6	23.0	34.6	35.9	36.2	49.7	49.0
A5	N5	S	86	65	38.9	35.5	31.7	27.9	26.2	31.9	32.6	30.0	46.1	47.0
A6	N6	M	87	74.1	39.3	37.2	33.2	29.1	27.5	30.8	33.4	32.2	47.6	48.5
A7	N7	M	89.4	78.9	41.6	37.6	35.0	30.7	28.1	31.5	33.0	31.7	49.7	49.0
A8	P2	M	90.2	76.5	39.2	38.94	37.46	32.36	28.24	34.18	35.82	32.46	52.15	52
A9	N8	M	90.1	75.5	41.8	30.5	37.0	33.4	28.0	38.0	38.1	35.6	54.2	54.8
	N9	M	90.2	67.1	42.7	39.3	37.9	31.4	27.5	35.5	37.5	35.2	54.9	53.9
	N10	M	91.1	74.5	40.0	37.5	36.0	30.0	27.9	33.9	37.8	33.2	49.7	51.0
A10	P3	M	91.4	73.9	39.54	38.39	38.33	33.5	28.47	33.69	36.3	32.6	51.39	52.35
A11	N11	L	93.2	91.9	40.0	35.7	34.3	30.3	29.3	35.4	35.4	35.0	50.8	50.9
A12	P4	L	93.4	79.9	40.33	38.56	37.49	33.32	30.01	33.2	33.19	33.7	50.58	50.72
A13	N12	L	93.7	79.1	41.6	37.0	34.1	30.8	26.5	38.0	39.0	37.5	52.0	51.6
	N13	L	94.8	81.4	44.1	39.0	35.8	32.4	29.5	34.5	35.1	34.9	52.6	51.5
A14	N14	L	95.7	78	43.8	38.2	35.3	31.7	28.0	34.8	36.2	35.5	51.0	51.9
A15	P5	L	95.8	74	41.23	36.29	34.96	29.04	26.19	37	37.38	36.19	50.9	52.08
A16	N15	L	97.3	69.3	40.1	38.2	35.6	31.5	26.4	34.4	35.0	35.5	51.8	51.1
A17	P6	L	97.4	72.2	37.95	38.38	37.31	32.04	26.84	33.69	35.53	34.42	50.91	50.81
	N16	XL	102.7	84.2	42.1	38.7	37.0	35.1	31.8	34.0	37.0	34.7	54.6	52.0
A18	N17	XL	106.2	91.4	39.6	40.1	38.6	35.6	32.0	36.0	36.1	35.0	52.8	53.8
	N18	XL	108.6	86.7	40.4	39.1	37.6	34.0	32.5	35.4	38.8	35.6	54.4	54.5
A19	N19	XL	122.1	109.7	44.3	42.9	40.2	37.7	34.2	37.3	39.2	36.8	54.8	55.8

Reliability of Motion Capture System

In order to test the reliability of the motion capture system, the data were collected and analyzed in two steps. In the first step, the participants were recorded three times using the motion capture system, in order to calculate the variation among repeated measures. In the second step, to test accuracy of the motion capture data, the measurements from the motion capture system were compared to the measurements from the 3D body scanner supported by ScanWorX Body Measure software. The surface measurements of body lengths were measured manually on the body scan using the virtual tools provided by the software. Lee and Ashdown (2005) demonstrated that 3D scan measurements were not significantly different from traditional manual measurements.

Reliability of Repeated Measures from the Motion Capture System

Intraclass correlation (ICC) was used to measure inter-rater reliability for three repeated measures from the motion capture system. The results of ICC tests show that values of all ICCs were close to 1.0, indicating that there was no variance between the three repeated measurements (see Table 5). High single measure reliability and average measure reliability indicated a high level of inter-rater consistency both on the single measure and on the average of the three measures. Because the average measure reliability was a little higher, an average of these repeated measures was used for subsequent analyses of measurements from the motion capture system.

Table 5. Results of Intraclass Correlation (ICC) Test for the Three Repeated Measurements from the Motion Capture System

	Single measure reliability	Average measure reliability
Shoulder width (S)	.96	.99
Back width (B)	.84	.94
Back arc at the armpit (BA)	.89	.96
Lower back arc (LB)	.98	.98
Waist (W)	.99	.99
Left side length (LS)	.97	.99

Center back length (CB)	.97	.99
Right side length (RS)	.95	.98
Right diagonal (RD)	.95	.98
Left diagonal (LD)	.93	.98

Comparison between the Measurements from the Motion Capture System and 3D Body Scanner

In order to determine if there were significant differences between the measurements from the motion capture system and the 3D body scanner, the two data sets were analyzed using a paired t-test. The results of the paired t-test are presented in Table 6. The measurements from the motion capture system showed a difference in values ranging from -.40 cm to .42cm when compared to the 3D body scan measurements taken from the standing posture. Analysis of the differences between the measurements taken for this study using a paired t-test revealed a significant difference in the lower back arc (LB), waist arc (W), left side length (LS), right diagonal (RD), and left diagonal (LD) ($p<.05$). The lower back arc (LB), waist arc (W), left side length (LS), right diagonal (RD), and left diagonal (LD) were a little bit larger in the scanned measurements than in the motion capture measurements. However, the difference values ranging from -.40 cm to .42cm were acceptable in this context because they were within the range of variability that can occur during the measurement process. Changes of .50cm have been observed when participants breathed normally during measurement (McKinnon & Istook, 2002). These results suggest that the data from the motion capture system are reliable and the motion capture system can be successfully used as a body measurement method.

Table 6. Difference Between Two Measuring Methods (unit: cm)

Measurement	Scanner		Motion Capture		Difference between Scanner and Motion Capture	t-value	p-value
	Mean	SD	Mean	SD			
Shoulder width (S)	40.71	2.00	40.33	2.09	.38	-1.59	.12
Back width (B)	37.44	2.43	37.84	2.03	-.40	1.23	.23
Back arc at the armpit (BA)	35.80	2.34	35.80	2.40	0	1.47	.15

Lower back arc (LB)	31.40	2.72	31.00	2.65	.40	-3.08*	.01
Waist (W)	27.84	2.84	27.53	2.81	.31	-2.30*	.03
Left side length (LS)	34.50	1.93	34.08	1.72	.42	-3.13*	.01
Center back length (CB)	35.90	1.96	35.95	2.03	-.05	.47	.65
Right side length (RS)	34.16	1.93	34.18	1.71	-.02	.13	.90
Right diagonal (RD)	51.10	2.57	50.74	2.34	.36	-2.40*	.03
Left diagonal (LD)	51.25	2.40	50.86	2.19	.39	-2.57*	.02

*: $p \leq .05$

Body Measurement Change in Motion

Using the motion capture system, the body measurement changes were examined in two motion tests: arm rotation and golf swing. After attaching the markers at locations on the body corresponding to the selected measurements, the participants' motions were recorded by capturing the X, Y, and Z positions of the markers. In order to determine how the motion affects body measurements, changes in the ten selected body measurements during the arm rotation and golf swing were analyzed. The measurement changes were established by the subtraction of the static dimensions from the maximum increases or maximum decreases. Individual changes and mean changes for each measurement were analyzed and the percent difference in changes between body sizes was investigated.

Motion Test 1: Arm Rotation

Measurement changes during arm rotation. Figure 15 is a graph of one participant that shows the trend of the ten selected measurement changes during arm rotation, and how the arm rotation motion affected the body measurement changes. All participants showed a similar trend of measurement changes corresponding to the motion. Although there was variation in actual change values, the maximum increase and decrease were found in the same body positions. Figure 15 is A10's body measurement change during the second arm rotation motion test. The actual values of individuals' maximum increases and decreases during the test are discussed in the following section.

The first measurement changes occurred when the participants started to raise their arms. While their arms were raised from the standing position to 90 degrees and then to 180 degrees, most measurements increased except the shoulder width (S) and the two diagonals (RD & LD). The maximum increase at the back width (B) occurred when arms were raised in front at 90 degrees. Right before the arms reached 180 degrees, the back width (B) decreased because the scapula goes up and comes together due to the shoulder elevation. When the arms reached 180 degrees, most measurements including the back arc at the armpit (BA), lower back arc (LB), left side length (LS), and right side length (RS) showed their maximum increases, but the shoulder width (S) showed a maximum decrease as well as RD and LD. When the arms were held out to the side, the back width (B), back arc at the armpit (BA), lower back arc (LB), left side length (LS), and right side length (RS) decreased because the scapula came together, but the shoulder width (S) started to increase. Because this motion test was limited to arm movement, very slight changes were found at the center back length (CB) and waist arc (W) whereas great changes occurred at the shoulder width (S), back width (B), back arc at the armpit (BA), and left side length (LS) and right side length (RS) during the test. The greatest maximum increase was found at the back arc at the armpit (BA), and the greatest maximum decrease was found at the shoulder width (S).

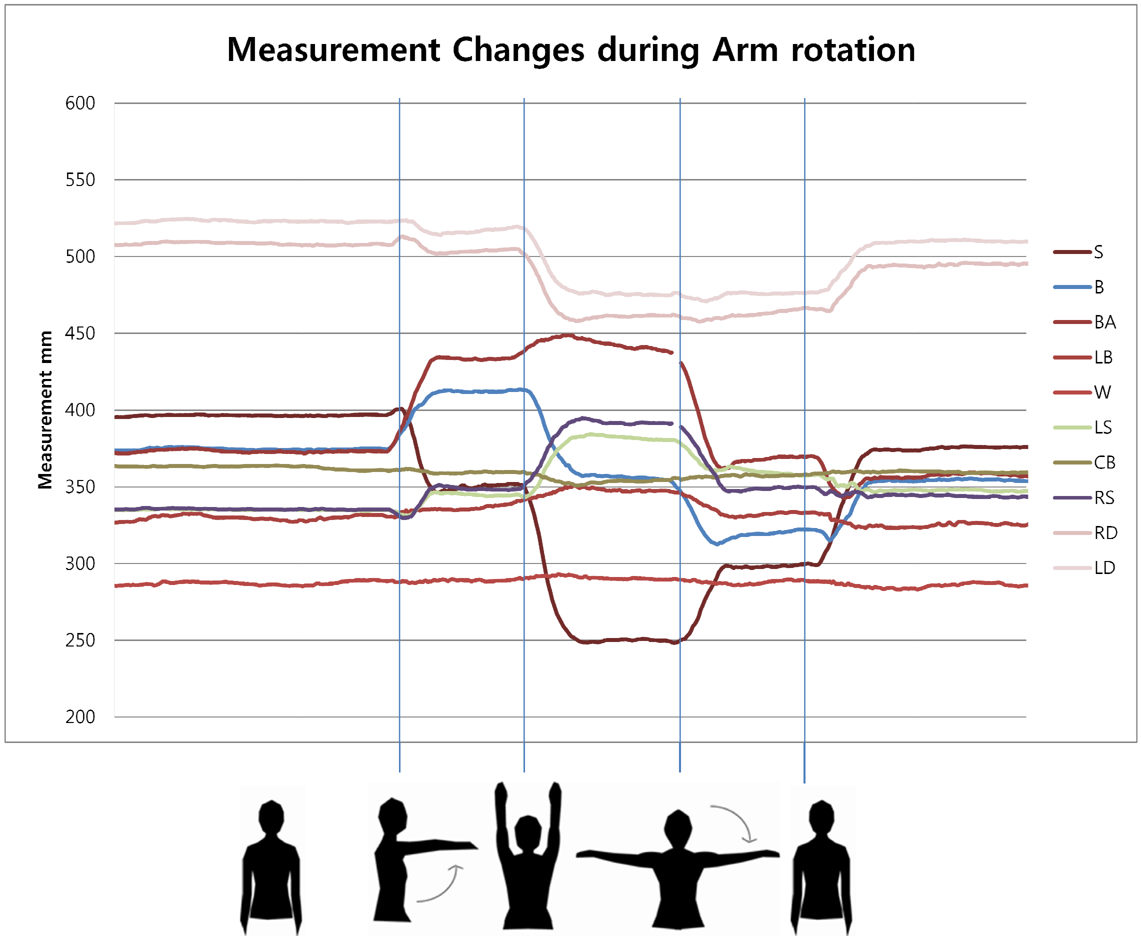
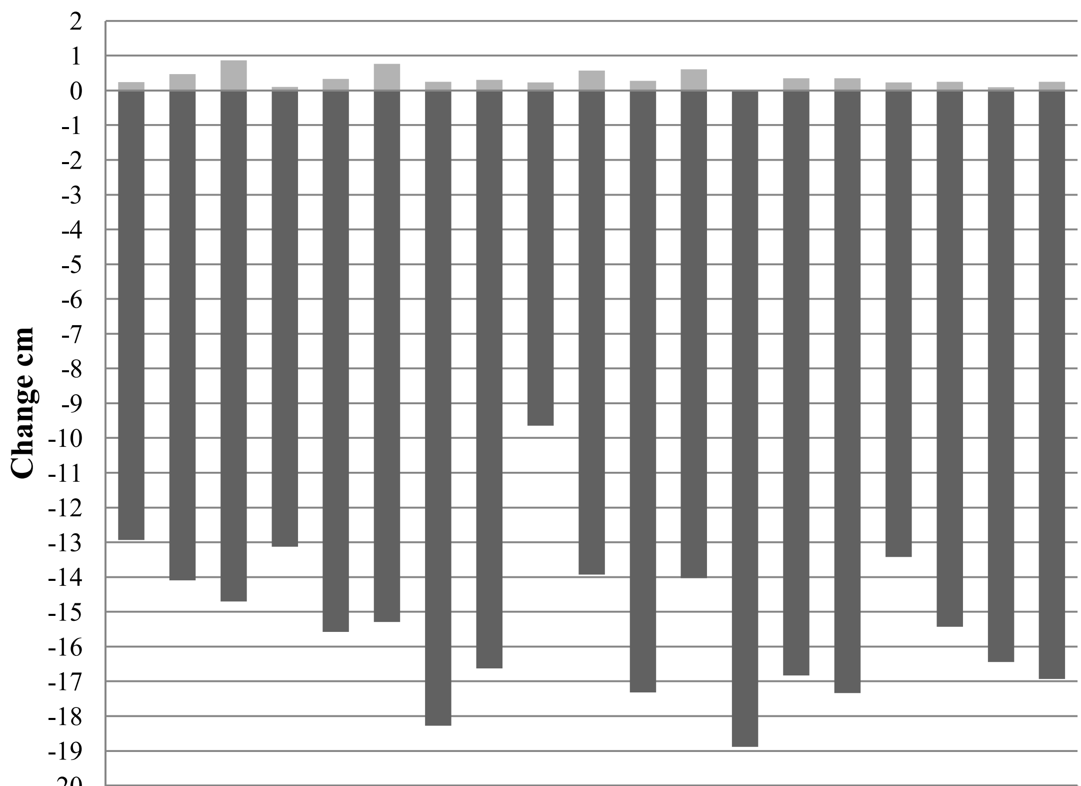


Figure 15. Measurement Change During Arm Rotation

Individual measurement changes. The arm rotation motion resulted in both increases and decreases in the body measurements. Each participant's maximum increase and decrease values at the shoulder width (S), back width (B), back arc at the armpit (BA), lower back arc (LB), waist arc (W), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) from the 19 participants in the arm rotation tests are presented in a graph format for each measurement location. Analysis of the individual measurement variations shows inter-participant changes in the ten measurements.

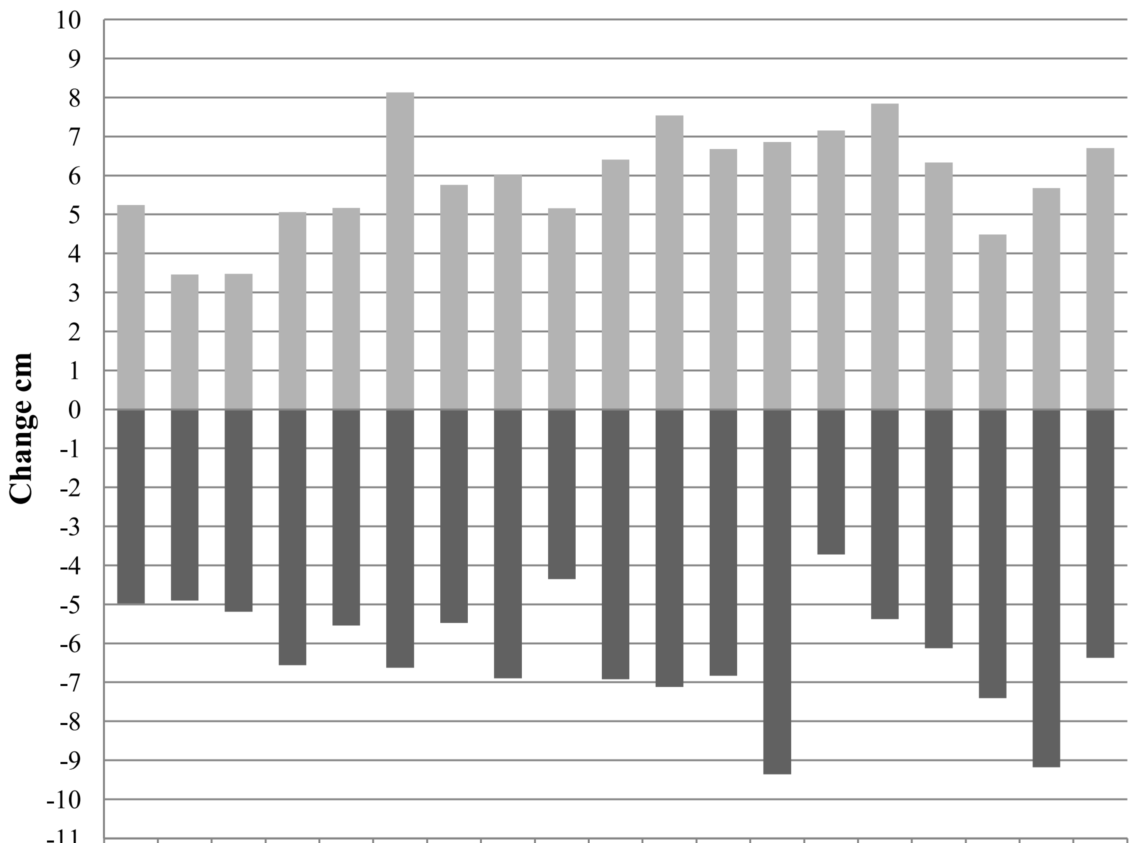
Shoulder width (S). Figure 16 shows the variation of maximum increase and maximum decrease values in the shoulder width (S) of the 19 participants during the arm rotation. The shoulder width increased from 0cm to .86cm and decreased from -9.56 cm to -18.9 cm. Overall, the shoulder width decreased more than 13cm except for A9, but increased less than 1cm. The decrease values are significantly higher than increases in all participants. The maximum decreases occurred when the participants' arms were held straight overhead, and the maximum increases were found when their arms were both raised 90 degrees.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	0.24	0.47	0.86	0.1	0.33	0.76	0.25	0.3	0.23	0.57	0.27	0.61	0	0.35	0.35	0.23	0.25	0.09	0.25
Decrease	-12.93	-14.09	-14.7	-13.13	-15.58	-15.29	-18.28	-16.63	-9.65	-13.93	-17.32	-14.03	-18.88	-16.83	-17.34	-13.42	-15.43	-16.44	-16.93

Figure 16. Individual Measurement Change at The Shoulder Width (S) in Arm Rotation

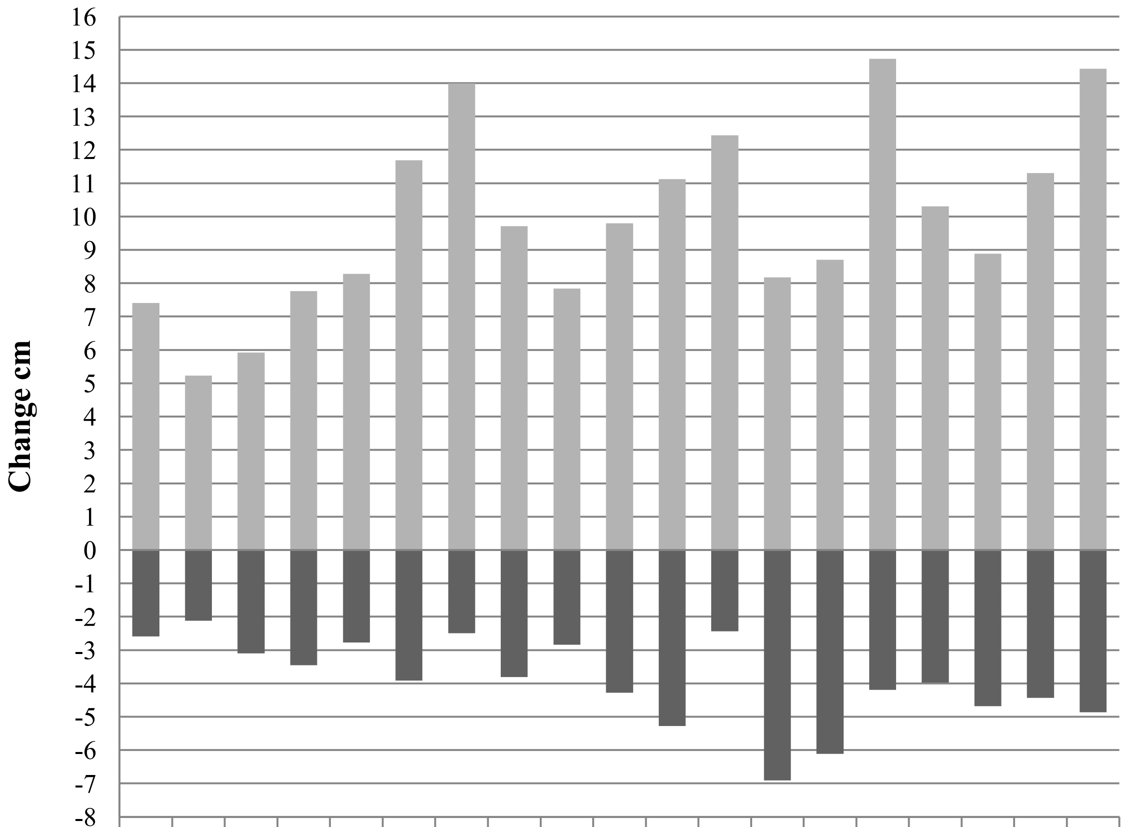
Back width (B). Figure 17 shows the variation of the maximum increase and maximum decrease values in the back width (B) of 19 participants during arm rotation. The back width increased from 3.45cm to 8.13cm, and decreased from -3.72cm to -9.36cm. The maximum increase and decrease values of each participant were similar. The maximum increase occurred when the arms were held up in front of the body at 90 degrees, and the maximum decrease was found when the arms were held out to the side of the body at 90 degrees.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	5.24	3.46	3.48	5.06	5.17	8.13	5.76	6.01	5.16	6.41	7.54	6.68	6.86	7.15	7.84	6.33	4.49	5.68	6.7
Decrease	-4.98	-4.9	-5.19	-6.56	-5.54	-6.63	-5.48	-6.9	-4.35	-6.92	-7.12	-6.83	-9.36	-3.72	-5.38	-6.13	-7.41	-9.18	-6.37

Figure 17. Individual Measurement Change at The Back Width (B) in Arm Rotation

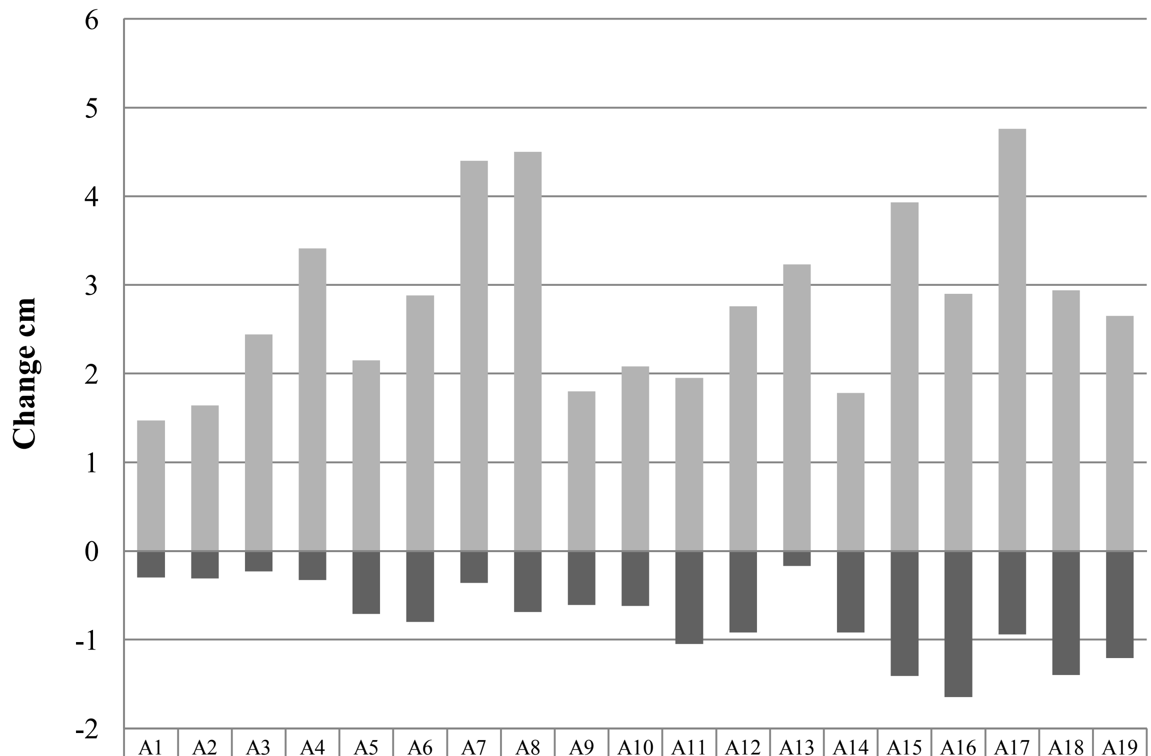
Back arc at the armpit (BA). Figure 18 shows the variation of the maximum increase and maximum decrease values in the back arc at the armpit level (BA) of 19 participants during arm rotation. The back arc at the armpit level increased from 5.23cm to 14.7cm, and decreased from -2.12cm to -6.91 cm. The maximum increases are higher than the maximum decreases in all participants. The maximum increase occurred when the arms were held up at 180 degrees, and the maximum decrease was found when the arms were held out to the side at 90 degrees. The maximum increase values show more variation, compared to other locations.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	7.41	5.23	5.92	7.76	8.28	11.69	13.99	9.71	7.84	9.8	11.12	12.44	8.18	8.7	14.73	10.31	8.89	11.3	14.43
Decrease	-2.59	-2.12	-3.1	-3.46	-2.77	-3.92	-2.5	-3.81	-2.84	-4.28	-5.28	-2.44	-6.91	-6.11	-4.19	-3.97	-4.68	-4.43	-4.87

Figure 18. Individual Measurement Change at The Back Arc at the Armpit Level (BA) in Arm Rotation

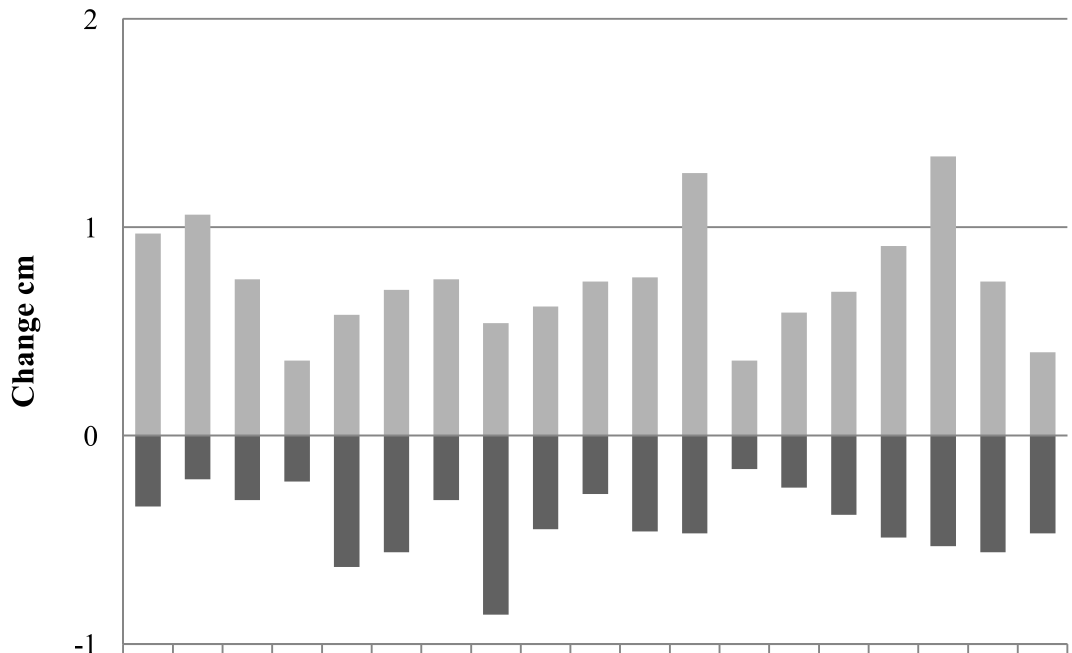
Lower back arc (LB). Figure 19 shows the variation of the maximum increase and maximum decrease values in the lower back arc (LB) of the 19 participants during arm rotation. The back arc increased from 1.47cm to 4.76 cm, and decreased from -0.17cm to -1.65cm. The maximum increase occurred when the arms were held up at 180 degrees, and the maximum decrease was found when the arms were held out to the side of the body at 90 degrees. The maximum increases are higher than the maximum decreases in all participants.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	1.47	1.64	2.44	3.41	2.15	2.88	4.4	4.5	1.8	2.08	1.95	2.76	3.23	1.78	3.93	2.9	4.76	2.94	2.65
Decrease	-0.3	-0.31	-0.23	-0.33	-0.71	-0.8	-0.36	-0.69	-0.61	-0.62	-1.05	-0.92	-0.17	-0.92	-1.41	-1.65	-0.94	-1.4	-1.21

Figure 19. Individual measurement change at the lower back arc (LB) in arm rotation

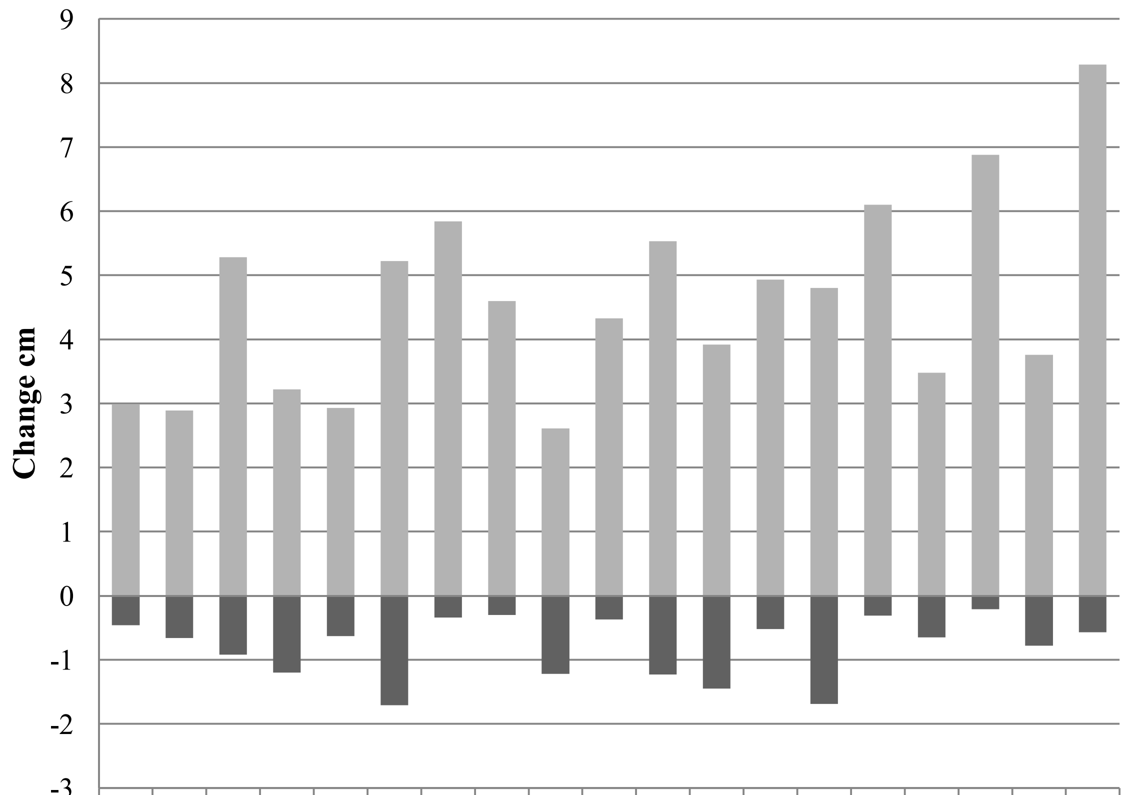
Waist arc (W). Figure 20 shows the variation of the maximum increase and maximum decrease values in the waist arc (W) for the 19 participants during arm rotation. The waist arc increased from 0.36 cm to 1.34 cm, and decreased from -0.16 cm to -0.86 cm. Because this test is associated with arm movement, the waist arc changes slightly. Figure 20 shows that there is no substantial change or variation among the participants.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	0.97	1.06	0.75	0.36	0.58	0.7	0.75	0.54	0.62	0.74	0.76	1.26	0.36	0.59	0.69	0.91	1.34	0.74	0.4
Decrease	-0.3	-0.2	-0.3	-0.2	-0.6	-0.6	-0.3	-0.9	-0.5	-0.3	-0.5	-0.5	-0.2	-0.3	-0.4	-0.5	-0.5	-0.6	-0.5

Figure 20. Individual measurement change at the waist arc (W) in arm rotation

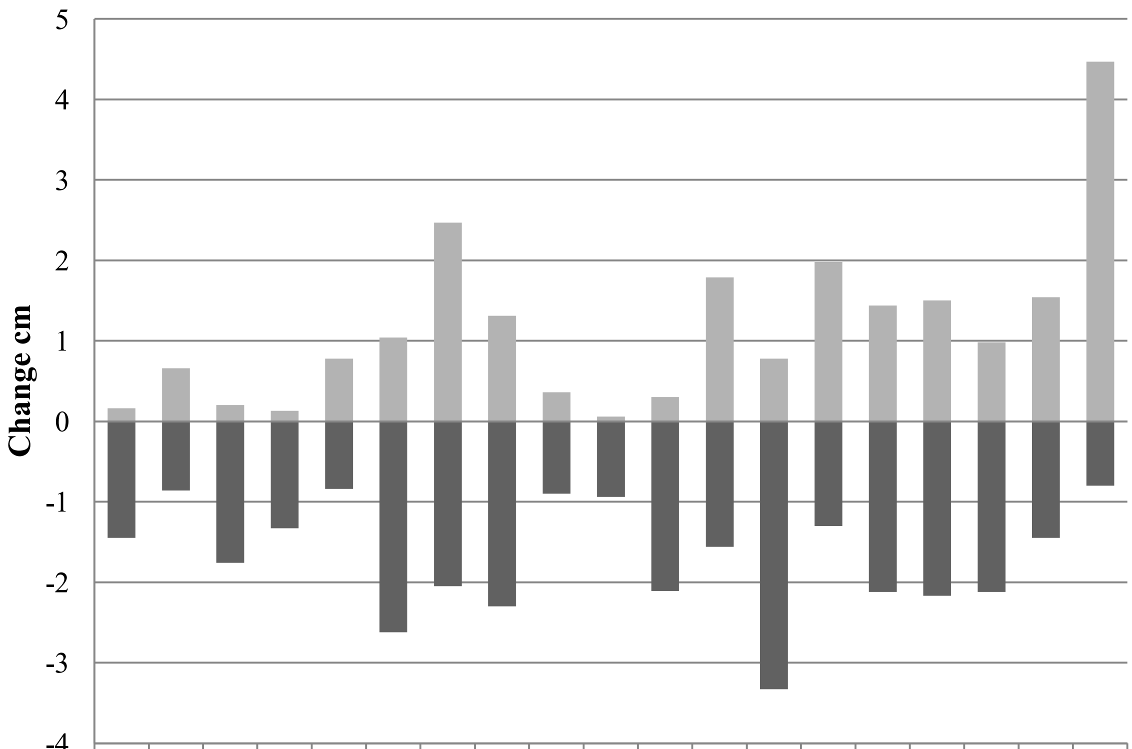
Left side length (LS). Figure 21 shows the variation of the maximum increase and maximum decrease values in the left side length (LS) for the 19 participants in arm rotation. The left side length increased from 2.61 cm to 8.29 cm, and decreased from -0.21 cm to -1.71 cm. The maximum increase occurred when the arms were held up at 180 degrees. Increases are much higher than the decreases for all participants; substantial decreases were not found.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	2.99	2.89	5.28	3.22	2.93	5.22	5.84	4.6	2.61	4.33	5.53	3.92	4.93	4.8	6.1	3.48	6.88	3.76	8.29
Decrease	-0.46	-0.66	-0.92	-1.2	-0.63	-1.71	-0.34	-0.3	-1.22	-0.37	-1.23	-1.45	-0.52	-1.69	-0.31	-0.65	-0.21	-0.78	-0.57

Figure 21. Individual measurement change at the left side length (LS) in arm rotation

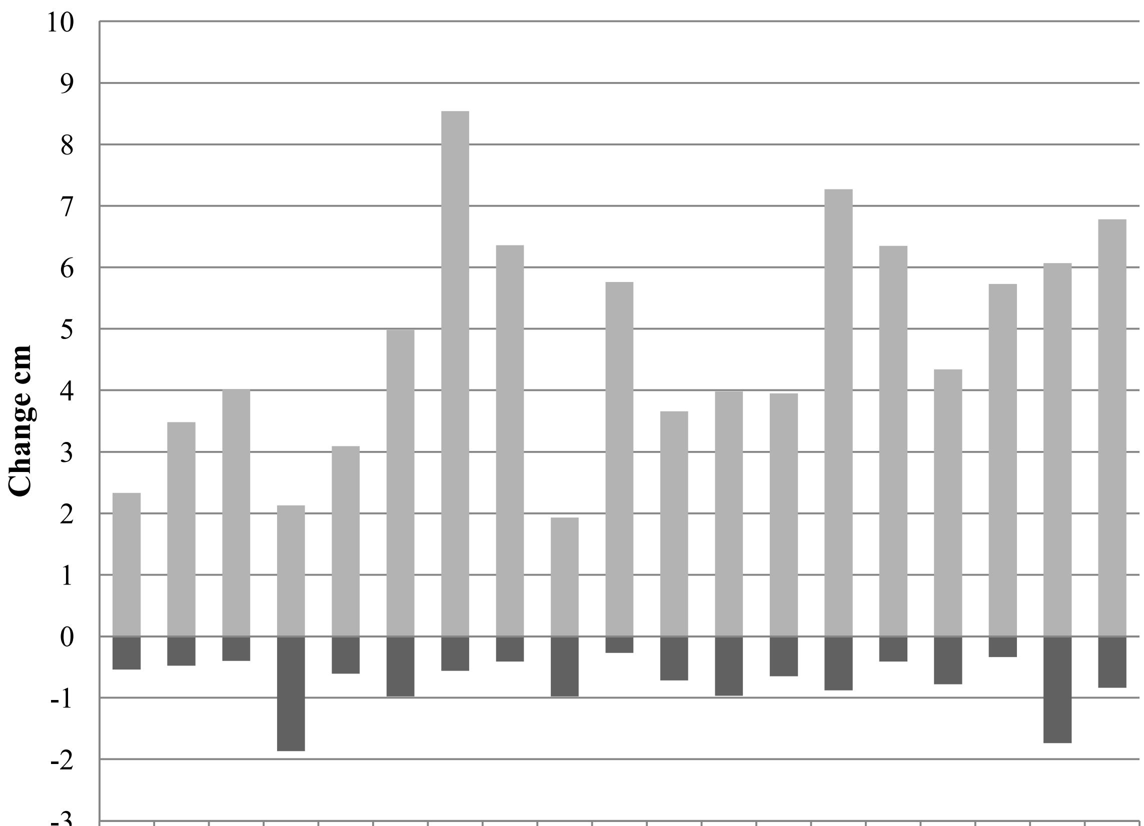
Center back length (CB). Figure 22 shows the variation of the maximum increase and maximum decrease values in the center back length (CB) for the 19 participants in arm rotation. The center back length increased from 0.06cm to 4.47cm and decreased from -0.09cm to -3.33 cm. The decreases were higher than increases, except for A19, but considerable variability among participants was found. This motion test involved only arm movement, though the spine is still involved in the movement as seen in the elongation.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	0.16	0.66	0.2	0.13	0.78	1.04	2.47	1.31	0.36	0.06	0.3	1.79	0.78	1.98	1.44	1.5	0.98	1.54	4.47
Decrease	-1.45	-0.86	-1.76	-1.33	-0.84	-2.62	-2.05	-2.3	-0.9	-0.94	-2.11	-1.56	-3.33	-1.3	-2.12	-2.17	-2.12	-1.45	-0.8

Figure 22. Individual measurement change at the center back length (CB) in arm rotation

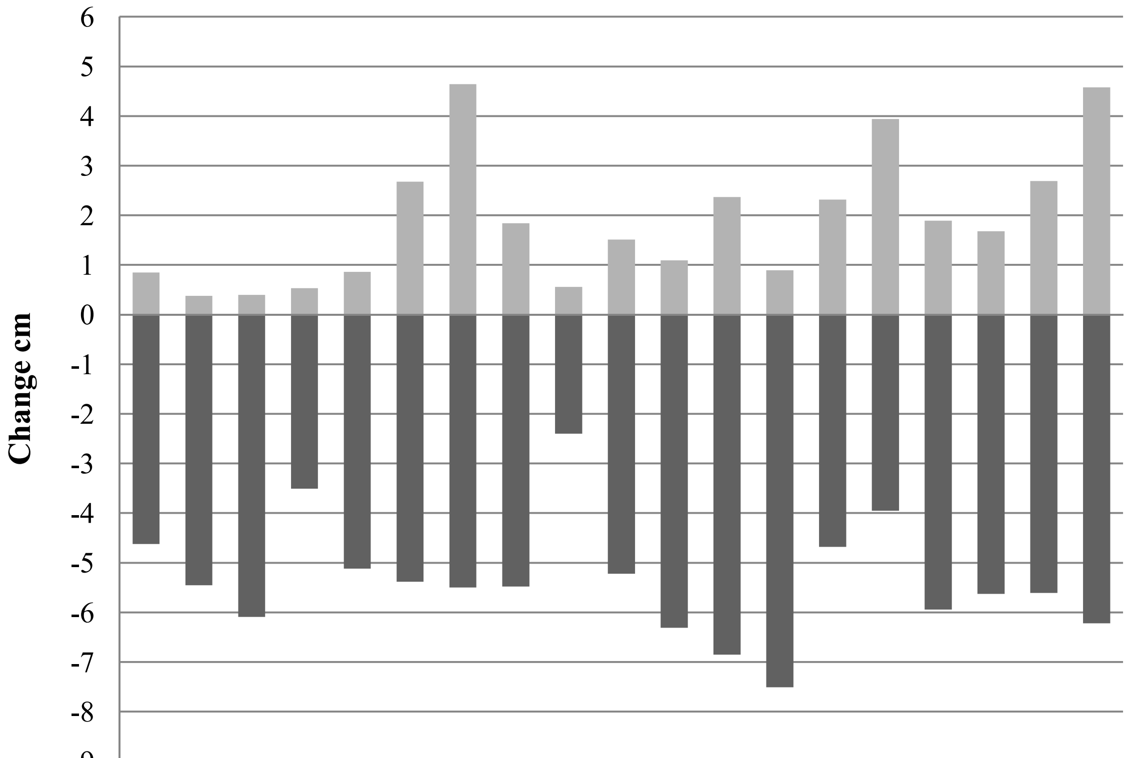
Right side length (RS). Figure 23 shows the variation of the maximum increase and maximum decrease values in the right side length (RS) for the 19 participants in arm rotation. The right side length increased from 1.93cm to 8.54 cm and decreased from -0.27cm to -1.87 cm. The increases are much higher than the decreases for all participants; substantial decreases were not found. The maximum increase occurred when the arms were held up at 180 degrees. Because this motion test involved the same movement on the left and right arm rotation, the results of the measurement changes in the right side length were similar to the left side length (LS).



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	2.33	3.48	4.01	2.13	3.09	4.98	8.54	6.36	1.93	5.76	3.66	3.98	3.95	7.27	6.35	4.34	5.73	6.07	6.78
Decrease	-0.54	-0.48	-0.4	-1.87	-0.61	-0.98	-0.56	-0.41	-0.98	-0.27	-0.72	-0.97	-0.65	-0.88	-0.41	-0.78	-0.34	-1.74	-0.84

Figure 23. Individual measurement change at the right side length (RS) in arm rotation

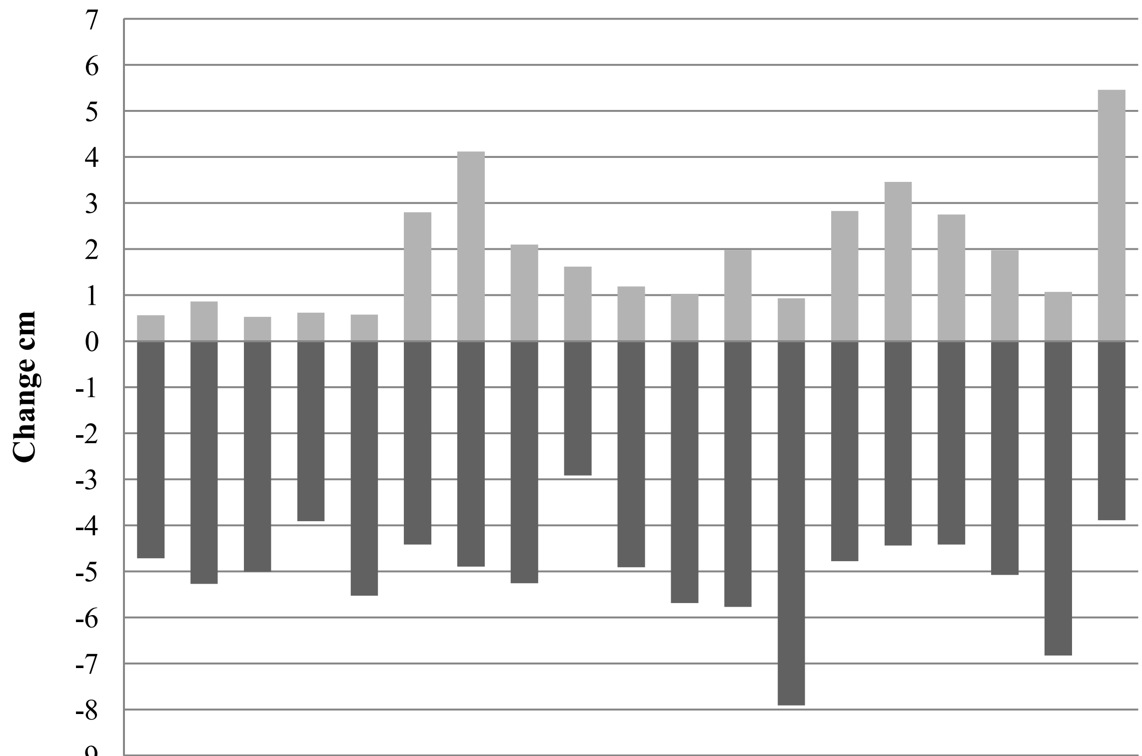
Right diagonal (RD). Figure 24 shows the variation of the maximum increases and maximum decreases of the right diagonal (RD) for the 19 participants in the arm rotation test. The right diagonal increased from 0.38 cm to 4.64 cm and decreased from -2.40 cm to -7.51 cm. The values of the maximum decreases were higher than the maximum increases among participants. The changes in the right diagonal were affected by the position of the shoulder tip; the maximum decrease was found when the arms were held up at 180 degrees.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	0.85	0.38	0.4	0.53	0.86	2.68	4.64	1.84	0.56	1.51	1.09	2.37	0.89	2.32	3.94	1.89	1.68	2.69	4.58
Decrease	-4.62	-5.45	-6.09	-3.51	-5.12	-5.38	-5.5	-5.48	-2.4	-5.22	-6.31	-6.85	-7.51	-4.68	-3.95	-5.94	-5.63	-5.61	-6.22

Figure 24. Individual measurement change at the right diagonal (RD) in arm rotation

Left diagonal (LD). Figure 25 shows the variation of the maximum increases and maximum decreases of the left diagonal (LD) for the 19 participants in arm rotation. The left diagonal increased from 0.53cm to 5.46 cm and decreased from -2.92 cm to -7.91 cm. The maximum decreases were higher than the maximum increases, except for A19. Because this motion test involved symmetrical movement on the left and right arm rotation, the results of the changes in the left diagonal were similar to the right diagonal.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Increase	0.56	0.86	0.53	0.62	0.58	2.8	4.12	2.1	1.62	1.19	1.03	1.98	0.93	2.83	3.46	2.75	1.97	1.07	5.46
Decrease	-4.72	-5.27	-5.01	-3.91	-5.53	-4.42	-4.9	-5.26	-2.92	-4.91	-5.69	-5.77	-7.91	-4.78	-4.44	-4.42	-5.08	-6.83	-3.89

Figure 25. Individual measurement change at the left diagonal (LD) in arm rotation

Mean measurement change in arm rotation. The results are presented showing mean measurement changes and mean percent changes of the ten selected measurements for the 19 participants (see Table 7 and Figure 26). The selected measurements increased from .34cm to 9.88cm (0.87% to 27.69%), and decreased from -15.31cm to -.42cm (-38.45% to -1.53%). The shoulder width (S), back width (B), and back arc at the armpit (BA) showed the highest change values and percent changes in dimensions in the arm rotation test. The increases were much higher than the decreases at the back arc at the armpit level (BA), lower back arc (LB), waist arc (W), left side length (LS), and right side length (RS) whereas the greatest decrease was found at the shoulder width (S). Similar increase and decrease values were found at the back width (B). These results suggest that the locations that increased or decreased the most were at the shoulder joint and scapula. These changes were related to flexion and extension of the shoulder during the arm rotation. In the case of the scapula elevation, the shoulder width (S) showed the greatest decrease (-15.31cm, -38.45%) whereas the increase value (.34cm, 0.87%) was very low. This result was the similar to the results of Wang, Mok, Li, and Kwok (2009) in shoulder width changes (-15.75cm). The movement of the scapula observed during the test could affect the body measurement changes because the scapula has more freedom of movement than other joints (Kapandji 1987). The back arc at the armpit level (BA) exhibited the greatest percent increase (27.69%).

Table 7. Mean measurement changes (cm) and percent changes (%) in arm rotation

Length	Measurement Change (cm)				Percent Change (%)			
	Maximum Increase		Maximum Decrease		Maximum Increase		Maximum Decrease	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder width (S)	.34	.22	-15.31	2.23	0.87	.58	-38.45	4.94
Back width (B)	5.96	1.33	-6.26	1.46	16.08	3.58	-16.84	3.47
Back arc at the armpit (BA)	9.88	2.73	-3.91	1.29	27.69	7.26	-10.88	3.17
Lower back arc (LB)	2.82	1.00	-.77	.44	9.31	3.26	-2.48	1.33
Waist (W)	.74	.27	-.42	.17	2.78	1.07	-1.53	.60
Left side length (LS)	4.61	1.51	-.80	.48	13.51	4.11	-2.37	1.44
Center back length (CB)	1.16	1.06	-1.68	.69	3.24	2.83	-4.76	1.90
Right side length (RS)	4.78	1.85	-.76	.43	14.03	5.52	-2.21	1.21

Right diagonal (RD)	1.88	1.35	-5.34	1.17	3.73	2.63	-10.72	2.26
Left diagonal (LD)	1.92	1.37	-5.03	1.08	3.78	2.61	-10.02	2.04

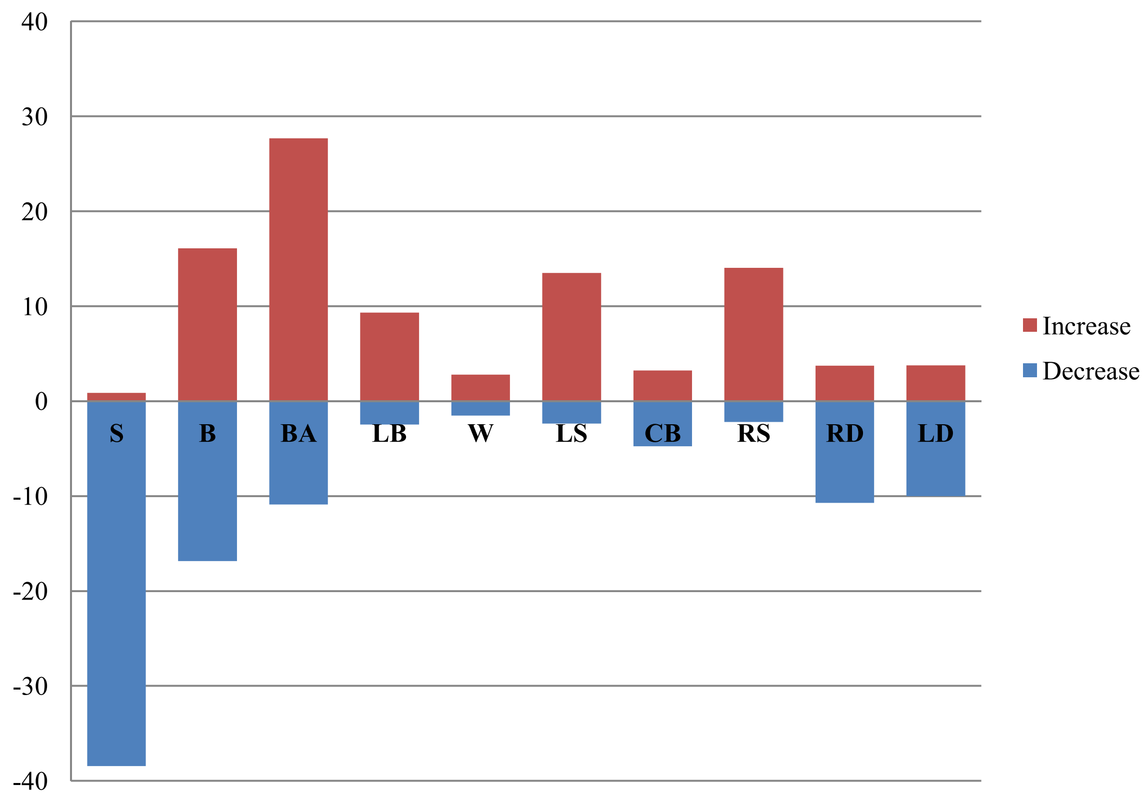


Figure 26. Mean percent change (%) in arm rotation

Mean comparison between body sizes. The body sizes were grouped into "small," "medium," "large", and xlarge", determined by the bust circumference (see Table 8). Five participants were size small with an average bust circumference of 81.04cm and average waist circumference of 68.30cm. Seven participants were size medium with an average bust circumference of 90.04cm and average waist circumference of 75.58cm. Eight participants were size large with an average bust circumference of 95.21cm and average waist circumference of 77.77cm. Four participants were size extra large with an average bust circumference of 114.15cm and average waist circumference of 100.55cm. The mean body measurements of the 19 participants in size small, medium, large, and xlarge are presented in Table 8.

Table 8. Mean body measurements across sizes for arm rotation test

	Size S (5)		Size M (5)		Size L (7)		Size XL (2)		Total (19)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bust circumference	**81.04**	3.52	**90.04**	2.05	**95.21**	1.80	**114.15**	11.24	**92.12**	10.23
Waist circumference	**68.30**	5.67	**75.58**	2.12	**77.77**	7.34	**100.55**	12.94	**77.10**	10.90
Shoulder width (S)	**37.57**	1.71	**40.16**	1.09	**40.62**	1.50	**41.30**	2.76	**39.77**	2.00
Back width (B)	**34.56**	1.52	**37.20**	1.21	**37.65**	1.58	**40.85**	.45	**37.06**	2.27
Back arc at the armpit (BA)	**32.06**	1.71	**35.96**	1.92	**36.66**	1.92	**39.91**	1.03	**35.61**	2.96
Lower back arc (LB)	**27.16**	1.32	**30.73**	1.77	**30.92**	1.72	**35.55**	1.05	**30.37**	2.85
Waist (W)	**23.76**	1.59	**27.48**	.71	**27.56**	1.72	**32.85**	2.38	**27.09**	2.98
Left side length (LS)	**32.56**	1.14	**33.22**	.84	**34.83**	1.61	**36.34**	1.58	**33.97**	1.75
Center back length (CB)	**33.95**	1.43	**35.14**	2.03	**35.92**	1.98	**37.68**	2.19	**35.38**	2.05
Right side length (RS)	**33.26**	2.09	**32.76**	.59	**35.16**	1.29	**35.70**	1.10	**34.09**	1.76
Right diagonal (RD)	**47.28**	1.28	**49.63**	1.92	**50.73**	1.12	**53.28**	1.03	**49.80**	2.26
Left diagonal (LD)	**47.59**	1.07	**50.04**	1.89	**51.14**	1.09	**54.54**	.65	**50.27**	2.41

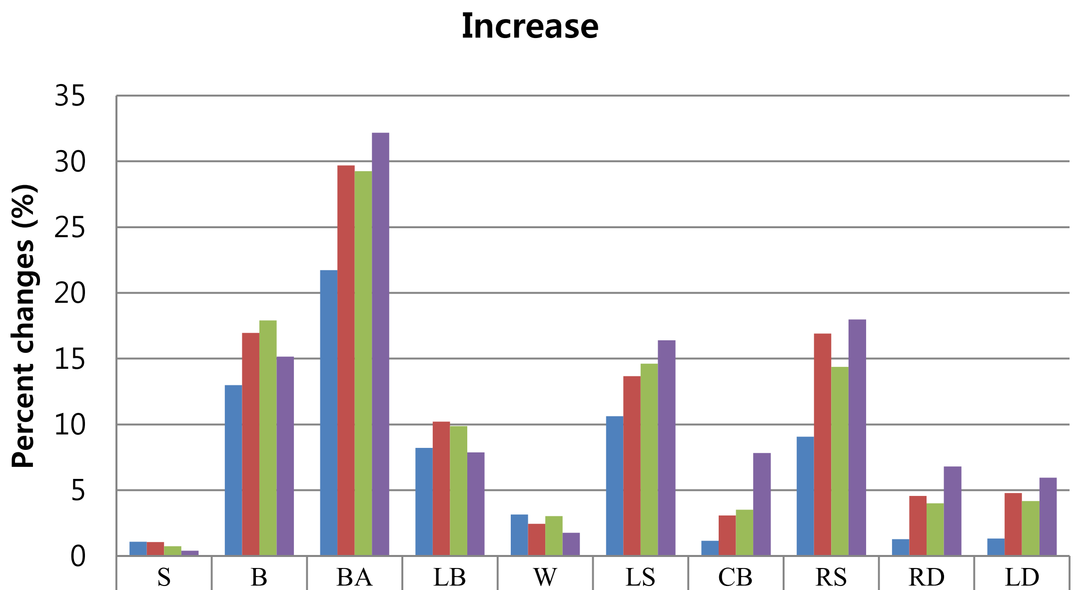
The results of descriptive statistics showed that the measurement changes in the shoulder width (S), back width (B), back arc at the armpit level (BA), lower back arc (LB), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) increased as the body sizes got larger (see Table 9 & Figure 27). No difference was found in the waist arc (W). The difference of the decrease across sizes was found at the shoulder width (S), back width (B), and lower back arc (LB). As the body sizes got larger, the decrease values were larger. For example, the decrease values of the back width (B) in size small was -5.43 cm (-15.74%), in size medium -6.06 cm (-16.27 %), in size large -6.56 cm (-17.40 %), and in size xlarge -7.78 cm (-19.06%).

The difference of the increase values across sizes was found at the back arc at the armpit level (BA), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD). The increase values in the back arc at the armpit level (BA), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) got larger as body sizes increased. For example, the maximum increase value of the left side length (LS) in size small was 3.46 cm (10.63 %), in size medium 4.52cm (13.68%), in size large 5.09 cm (14.62%), and in size xlarge 6.03 cm (16.40 %).

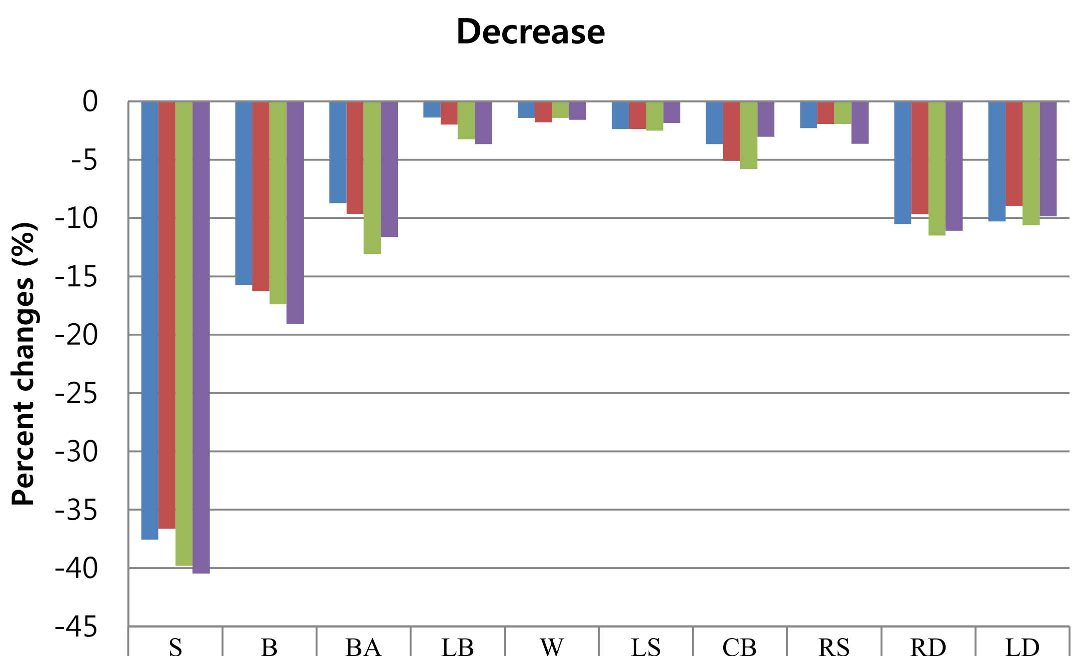
The difference of the increase value was also found at the right side length (RS), right diagonal (RD), and left side length (LD) although the changes did not consistently get larger across sizes. The values in size medium were larger than the values in size large. However, the least increase value was found in size small and the greatest increase value was found in size xlarge. For example, the maximum increase value of the right diagonal (RD) in size small was .60 cm (1.28%), in size medium 2.25cm (4.56%), in size large 2.03 cm (4.00%), and in xlarge 3.64 cm (6.80%), and the maximum increase value of the left diagonal (LD) in size small was .63cm (1.33%), in size medium 2.37 cm (4.79%), in size large 2.14 cm (4.18%), and in size xlarge 3.27 cm (5.95 %). Overall, the changes in measurements during arm rotation were smaller in size small and larger in size large and xlarge.

Table 9. Mean measurement changes (cm) and percent changes (%) across sizes for arm rotation test

	Measurement Change		Size S (5)		Size M (5)		Size L (7)		Size XL (2)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder width (S)	Increase	cm	.40	.29	.42	.23	.29	.18	.17	.11
		%	1.07	.77	1.06	.60	.73	.46	.40	.25
	Decrease	cm	**-14.09**	1.10	**-14.76**	3.28	**-16.18**	1.96	**-16.69**	.35
		%	**-37.57**	3.60	**-36.63**	7.48	**-39.81**	4.44	**-40.46**	1.86
Back width (B)	Increase	cm	4.48	.93	6.29	1.12	6.70	1.10	6.19	.72
		%	12.99	2.72	16.97	3.42	17.91	3.53	15.15	1.60
	Decrease	cm	**-5.43**	.68	**-6.06**	1.12	**-6.56**	1.76	**-7.78**	1.99
		%	**-15.74**	2.01	**-16.27**	2.92	**-17.40**	4.51	**-19.06**	5.07
Back arc at the armpit (BA)	Increase	cm	**6.92**	1.29	**10.61**	2.33	**10.62**	2.35	**12.87**	2.21
		%	**21.72**	4.75	**29.69**	7.52	**29.70**	7.69	**32.17**	4.71
	Decrease	cm	-2.81	.51	-3.47	.76	-4.80	1.47	-4.65	.31
		%	-8.75	1.43	-9.63	1.94	-13.09	3.91	-11.65	.48
Lower back arc (LB)	Increase	cm	2.22	.77	3.13	1.27	3.04	1.05	2.80	.21
		%	8.21	3.03	10.21	4.11	9.87	3.43	7.88	.81
	Decrease	cm	**-.38**	.19	**-.62**	.16	**-1.01**	.47	**-1.31**	.13
		%	**-1.39**	.69	**-2.01**	.55	**-3.26**	1.54	**-3.68**	.49
Waist (W)	Increase	cm	.74	.29	.67	.09	.84	.35	.57	.24
		%	3.15	1.31	2.44	.30	3.04	1.20	1.77	.86
	Decrease	cm	-.34	.17	-.49	.23	-.39	.14	-.52	.06
		%	-1.41	.62	-1.80	.86	-1.41	.49	-1.58	.31
Left side length (LS)	Increase	cm	**3.46**	1.02	**4.52**	1.22	**5.09**	1.19	**6.03**	3.20
		%	**10.63**	3.08	**13.68**	3.95	**14.62**	3.45	**16.40**	8.10
	Decrease	cm	-.77	.29	-.79	.64	-.87	.59	-.68	.15
		%	-2.37	.83	-2.38	1.96	-2.51	1.73	-1.87	.49
Center back length (CB)	Increase	cm	**.39**	.31	**1.05**	.94	**1.25**	.59	**3.01**	2.07
		%	**1.16**	.96	**3.08**	2.86	**3.52**	1.75	**7.83**	5.04
	Decrease	cm	-1.25	.40	-1.76	.79	-2.10	.64	-1.13	.46
		%	-3.66	1.12	-5.10	2.47	-5.80	1.49	-3.03	1.40
Right side length (RS)	Increase	cm	**3.01**	.78	**5.51**	2.40	**5.04**	1.41	**6.43**	.50
		%	**9.08**	2.42	**16.92**	7.52	**14.37**	4.11	**17.99**	.85
	Decrease	cm	-.78	.61	-.64	.33	-.68	.23	-1.29	.64
		%	-2.30	1.65	-1.95	.99	-1.94	.69	-3.64	1.89
Right diagonal (RD)	Increase	cm	**.60**	.24	**2.25**	1.54	**2.03**	1.01	**3.64**	1.34
		%	**1.28**	.52	**4.56**	3.21	**4.00**	2.00	**6.80**	2.38
	Decrease	cm	-4.96	.97	-4.80	1.34	-5.84	1.22	-5.92	.43
		%	-10.51	2.16	-9.66	2.70	-11.50	2.37	-11.10	.59
Left diagonal (LD)	Increase	cm	**.63**	.13	**2.37**	1.15	**2.14**	.94	**3.27**	3.10
		%	**1.33**	.30	**4.79**	2.46	**4.18**	1.84	**5.95**	5.62
	Decrease	cm	-4.89	.62	-4.48	.92	-5.44	1.22	-5.36	2.08
		%	-10.29	1.48	-8.96	1.80	-10.62	2.21	-9.85	3.93



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	1.07	12.99	21.72	8.21	3.15	10.63	1.16	9.08	1.28	1.33
M	1.06	16.97	29.69	10.21	2.44	13.68	3.08	16.92	4.56	4.79
L	0.73	17.91	29.26	9.87	3.04	14.62	3.52	14.37	4	4.18
XL	0.4	15.15	32.17	7.88	1.77	16.4	7.83	17.99	6.8	5.95



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	-37.57	-15.74	-8.75	-1.39	-1.41	-2.37	-3.66	-2.3	-10.51	-10.29
M	-36.63	-16.27	-9.63	-2.01	-1.8	-2.38	-5.1	-1.95	-9.66	-8.96
L	-39.81	-17.4	-13.09	-3.26	-1.41	-2.51	-5.8	-1.94	-11.5	-10.62
XL	-40.46	-19.06	-11.65	-3.68	-1.58	-1.87	-3.03	-3.64	-11.1	-9.85

Figure 27. Percent change (%) across sizes in arm rotation

Motion Test 2: Golf Swing

Measurement changes during golf swing. Figure 28 shows the trend of the ten selected measurement changes during the golf swing, and how the golf swing motion affected the measurement changes. Although there was a variation in actual change values, the trend of measurement changes during the motion test was similar among the participants. Golf swings are unique to each individual, thus more variability of measurement change was found among participants. Figure 28 is participant N5's body measurement change during the second golf swing motion test. The actual values of individuals' maximum increases and decreases during the test are discussed in the following section.

The first measurement changes occurred the moment the participants got into position for starting the golf swing; all measurements increased. The maximum increase at the shoulder width (S) and the lower back arc (LB) occurred at the initiation phase. Dramatic measurement changes were found when the participants moved from the back swing to the downswing and from the acceleration to the follow through.

When the participants began the takeaway, the shoulder width (S), left side length (LS), left diagonal (LD) decreased while the back width (B), back arc at the armpit level (BA), lower back arc (LB), right side length (RS), and right diagonal (RD) increased. The back width (B) and back arc at the armpit (BA) showed the maximum increase.

When they started the backswing, the shoulder width (S), back width (B), back arc at the armpit level (BA) and left diagonal (LD) decreased, and the right side length (RS) and right diagonal (RD) continued increasing. The maximum increase at the right diagonal (RD) and the maximum decrease at the shoulder width (S) and left diagonal (LD) occurred at the top of backswing.

During the down swing, the shoulder width (S), back width (M1), back arc at the armpit level (BA), lower back arc (LB), left side length (LS), and left diagonal (LD) increased while right side length (RS) decreased. The left side length (LS) increased the most at this phase.

When they performed the acceleration to follow-through, the shoulder width (S), back width (B), back arc at the armpit level (BA,) left side length (LS), and right diagonal (RD) decreased, while waist arc (W), right side length (RS), and left diagonal (LD) increased. The maximum decrease at the back width (B), back arc at the armpit level (BA), and right diagonal (RD) occurred at the follow-through. The waist arc (W), right side length (RS) and the left diagonal (LD) showed the maximum increase at this phase.

During the golf swing, great changes were found at the shoulder width (S), back arc at the armpit level (BA), lower back arc (B), left side length (LS), center back length (CB), right diagonal (RD), and left diagonal (LD) whereas slight changes occurred at the shoulder width (S), back width (B), back arc at the armpit (BA), and lower back arc (LB) and waist arc (W). These results suggest that the highest changes in measurement occurred at the shoulder joint and scapula, which is similar to the arm rotation test.

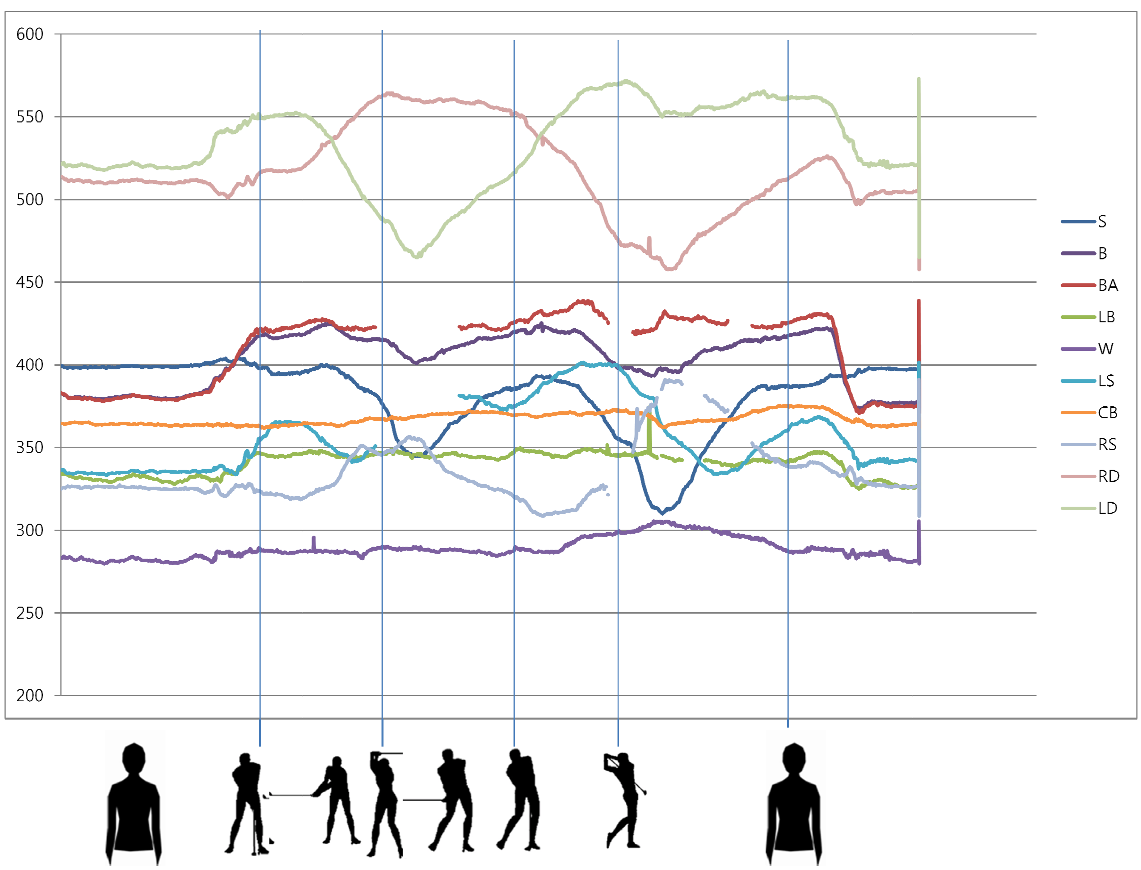
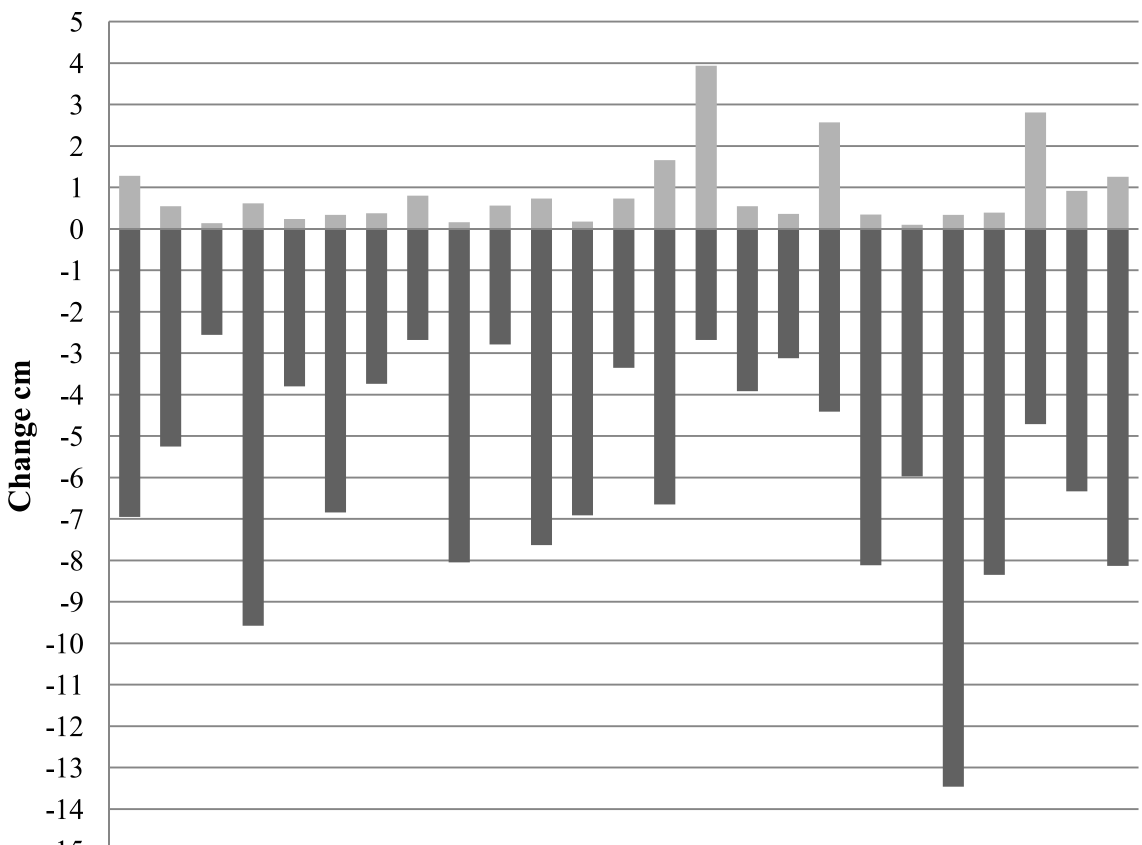


Figure 28. Measurement change during golf swing for Participant N5

Individual Measurement Changes. The maximum increase and decrease values of the ten selected measurements of the 25 participants in the golf swing test are presented. Each participant's maximum increase and decrease values in the shoulder width (S), back width (B), back arc at the armpit level (BA), lower back arc (LB), waist arc (W), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) during the golf swing are presented in a graph format.

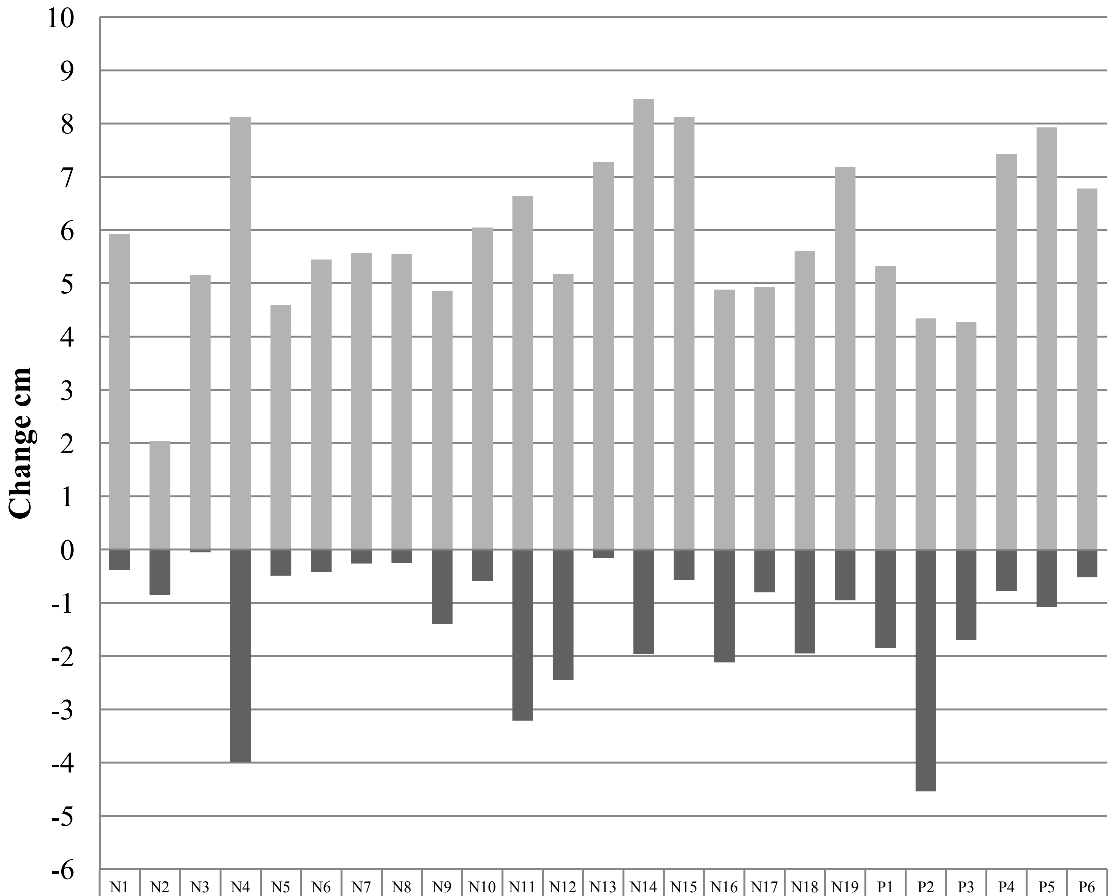
Shoulder width (S). Figure 29 shows the variation of the maximum increase and maximum decrease values in the shoulder width (S) for the 25 participants during the golf swing. The shoulder width increased from 0.1 cm to 3.94 cm, and decreased from -2.56 cm to -13.46 cm. The decreases were higher than the increases, except for N15. The shoulder width was observed to be highly variable among participants. The shoulder width decreased most when participants performed follow-through; thus, the maximum decrease value in the shoulder width was mostly affected by the variation of golf swing from participants. Expert golfers showed the highest maximum decreases; participant P2 showed the greatest maximum decrease.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	1.28	0.55	0.14	0.62	0.24	0.34	0.38	0.8	0.16	0.56	0.73	0.18	0.73	1.66	3.94	0.55	0.36	2.57	0.35	0.1	0.34	0.39	2.81	0.92	1.26
Decrease	-6.95	-5.25	-2.56	-9.58	-3.8	-6.84	-3.74	-2.68	-8.05	-2.79	-7.63	-6.91	-3.35	-6.65	-2.68	-3.92	-3.12	-4.41	-8.12	-5.97	-13.5	-8.35	-4.71	-6.33	-8.13

Figure 29. Individual measurement change at the shoulder width (S) in golf swing

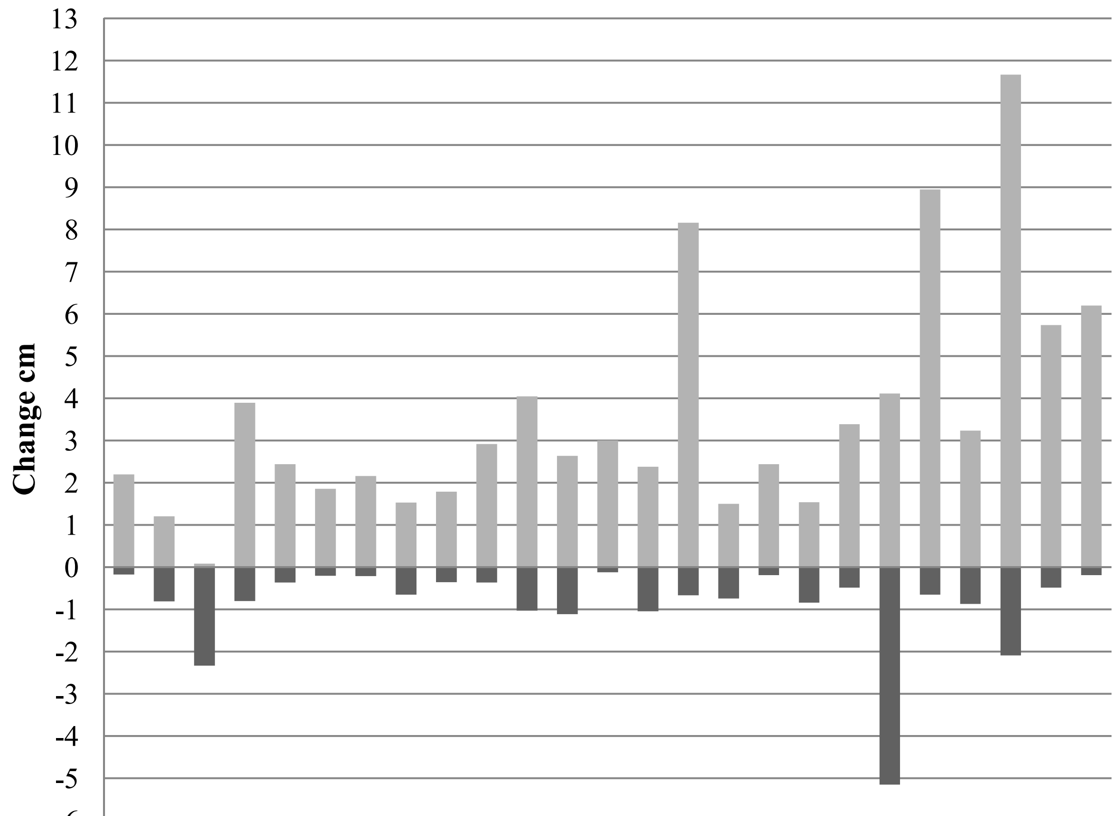
Back width (B). Figure 30 shows the variation of the maximum increase and maximum decrease values in the back arc (B) for the 25 participants during the golf swing. The back width increased from 2.04 cm to 8.46 cm, and decreased -0.05 cm to -4.54 cm. The increases are much higher than the decreases. There is no difference in the measurement changes between the novice and expert golfers.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	5.92	2.04	5.16	8.13	4.59	5.45	5.57	5.55	4.85	6.05	6.64	5.17	7.28	8.46	8.13	4.88	4.93	5.61	7.19	5.32	4.34	4.27	7.43	7.93	6.78
Decrease	-0.38	-0.85	-0.05	-3.99	-0.49	-0.42	-0.26	-0.25	-1.4	-0.59	-3.21	-2.45	-0.16	-1.96	-0.57	-2.12	-0.8	-1.95	-0.95	-1.85	-4.54	-1.7	-0.78	-1.08	-0.52

Figure 30. Individual measurement change at the back width (B) in golf swing

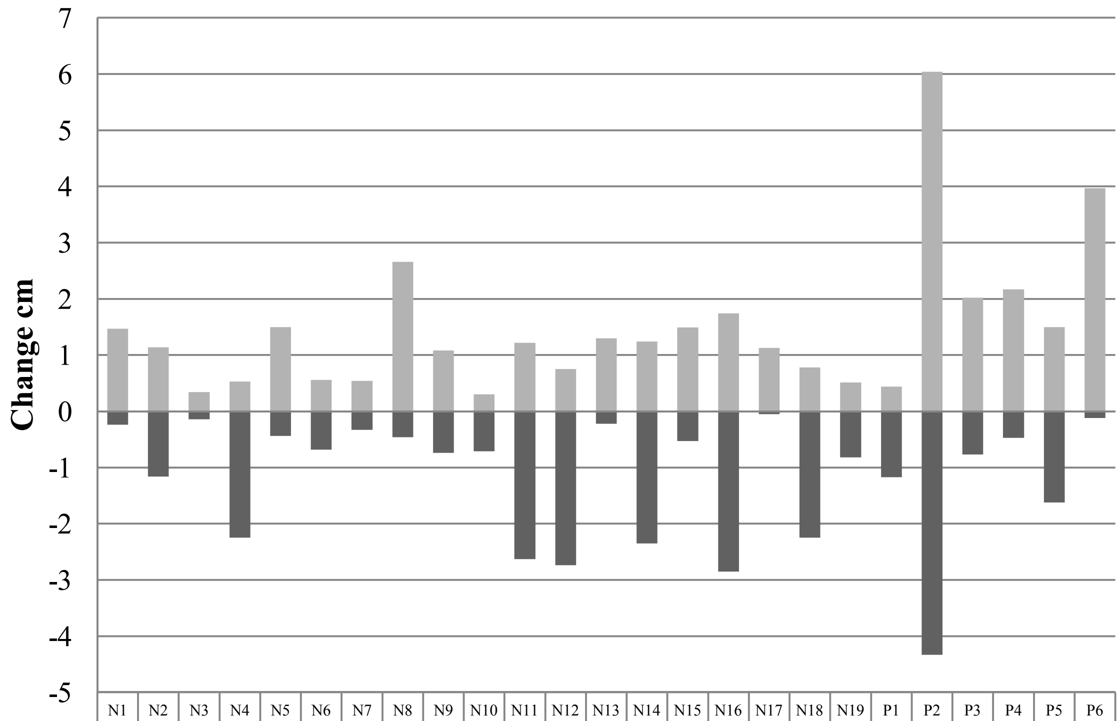
Back arc at the armpit level (BA). Figure 31 shows the variation of the maximum increase and maximum decrease values in the back arc at the armpit level (BA) for the 25 participants during the golf swing. The back arc at the armpit level increased from 0.09 cm to 11.67 cm, and decreased from -0.17 cm to -5.15 cm. The increases are much higher than the decreases, except for N3 and P1. Expert golfers, P2 and P4, showed the highest increase of 8.95 to 11.67cm.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	2.2	1.21	0.09	3.9	2.44	1.86	2.16	1.53	1.79	2.92	4.05	2.64	3	2.38	8.16	1.5	2.44	1.54	3.39	4.12	8.95	3.24	11.67	5.74	6.2
Decrease	-0.17	-0.81	-2.33	-0.8	-0.36	-0.2	-0.21	-0.65	-0.35	-0.36	-1.03	-1.11	-0.12	-1.04	-0.66	-0.74	-0.19	-0.84	-0.48	-5.15	-0.65	-0.87	-2.09	-0.48	-0.19

Figure 31. Individual measurement change at the back arc at the armpit level (BA) in golf swing

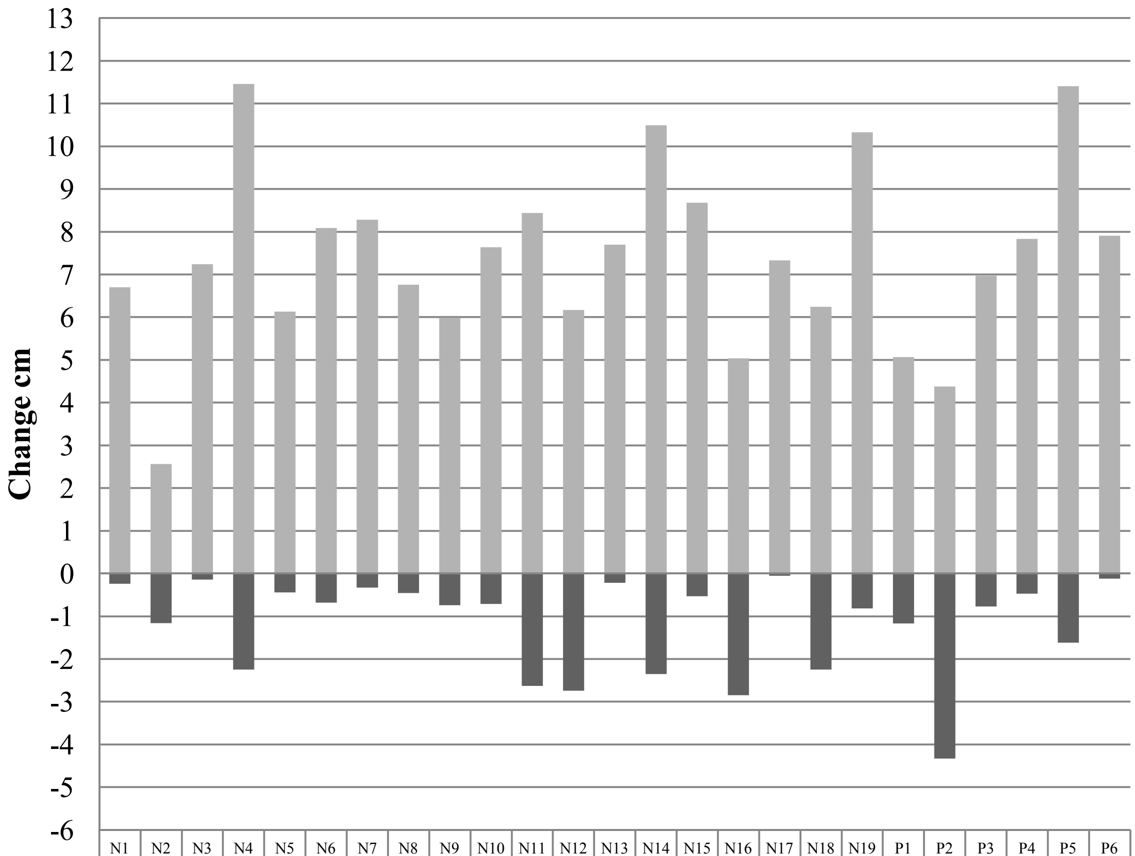
Lower back arc (LB). Figure 32 shows the variation of the maximum increase and maximum decrease values in the lower back arc (LB) for the 25 participants during the golf swing. The lower back arc increased from 0.30 cm to 6.04 cm, and decreased from -0.05 cm to -4.33 cm. P2 showed the greatest maximum increase and decrease.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	1.47	1.14	0.34	0.53	1.5	0.56	0.54	2.66	1.08	0.3	1.22	0.75	1.3	1.24	1.49	1.74	1.13	0.78	0.51	0.44	6.04	2.02	2.17	1.5	3.97
Decrease	-0.24	-1.16	-0.14	-2.25	-0.44	-0.68	-0.33	-0.46	-0.74	-0.71	-2.63	-2.74	-0.22	-2.35	-0.53	-2.85	-0.05	-2.25	-0.82	-1.17	-4.33	-0.77	-0.47	-1.62	-0.12

Figure 32. Individual measurement change at the lower back arc (LB) in golf swing

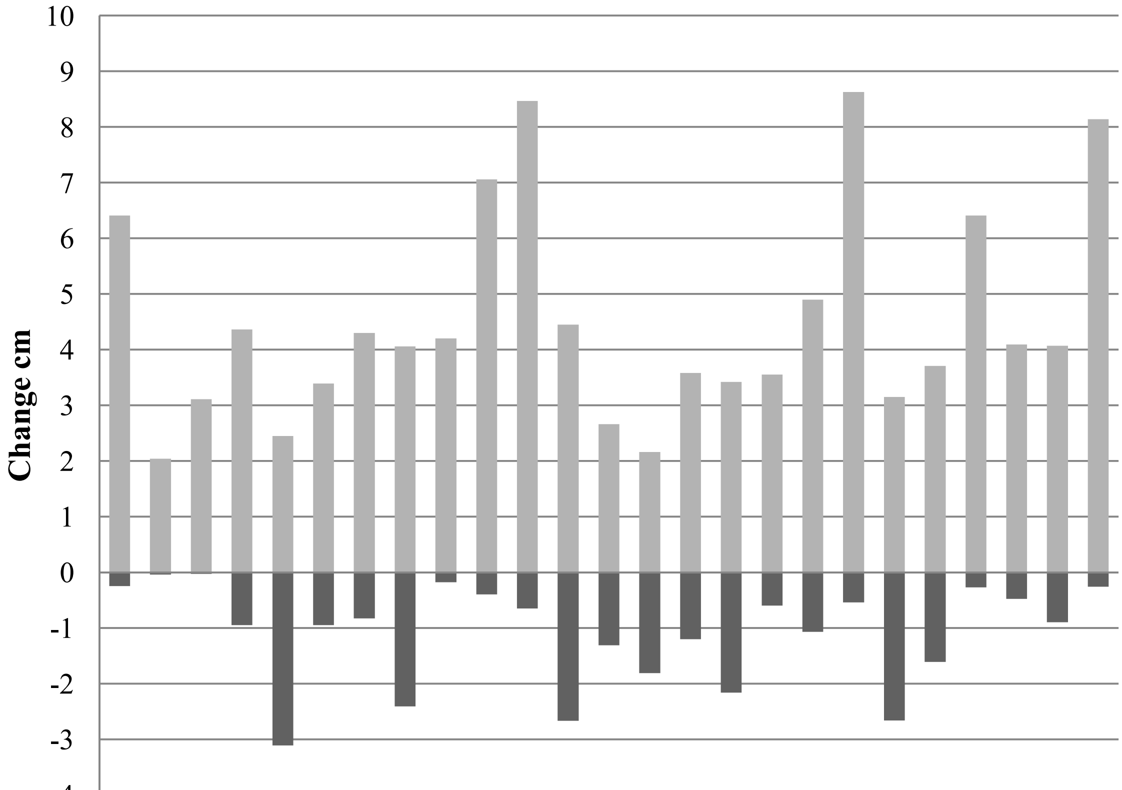
Waist arc (W). Figure 33 shows the variation of the maximum increase and maximum decrease values in the waist arc (W) for the 25 participants during the golf swing. The waist arc increased from 2.56 cm to 11.46 cm, and decreased from -0.05cm to 4.38 cm. The increases are much higher than the decreases.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	6.7	2.56	7.24	11.46	6.13	8.09	8.28	6.76	5.99	7.64	8.44	6.17	7.7	10.49	8.68	5.04	7.33	6.24	10.33	5.07	4.38	6.97	7.83	11.41	7.91
Decrease	-0.24	-1.16	-0.14	-2.25	-0.44	-0.68	-0.33	-0.46	-0.74	-0.71	-2.63	-2.74	-0.22	-2.35	-0.53	-2.85	-0.05	-2.25	-0.82	-1.17	-4.33	-0.77	-0.47	-1.62	-0.12

Figure 33. Individual measurement change at the waist arc (W) in golf swing

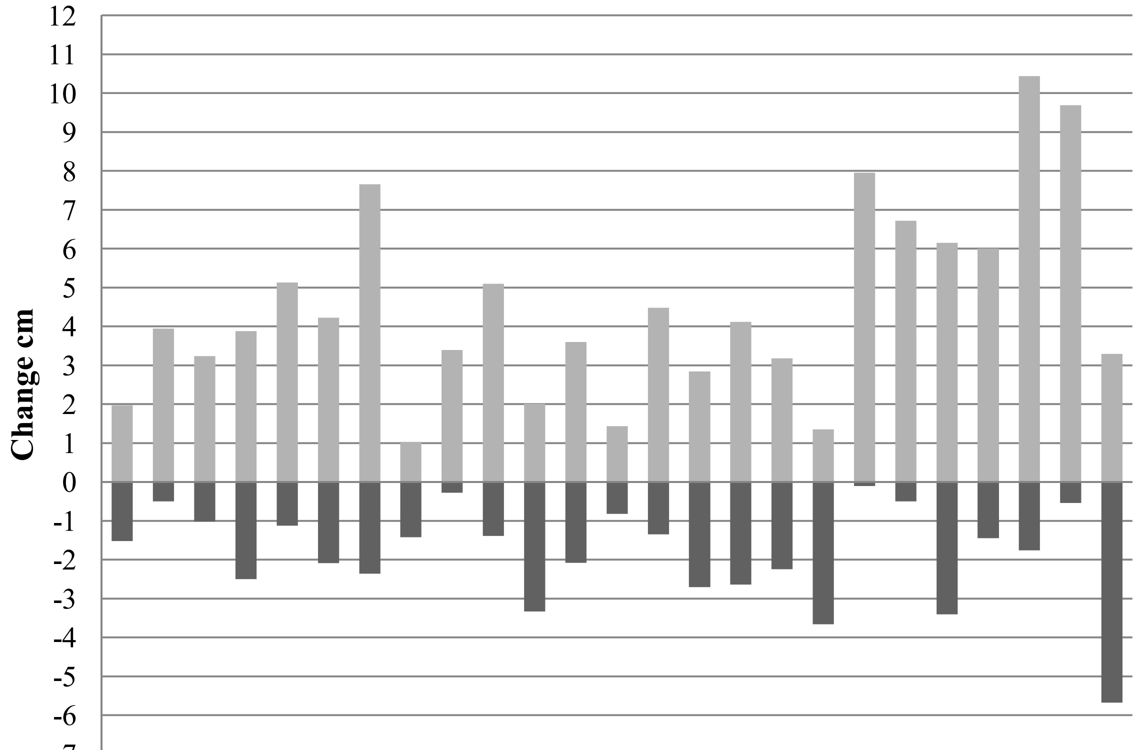
Left side length (LS). Figure 34 shows the variation of the maximum increase and maximum decrease values in the left side length (LS) for the 25 participants during the golf swing. The left side length increased from 2.04 cm to 8.63 cm, and decreased from -0.03 cm to -3.11 cm. The increases are higher than the decreases, except for N5. No substantial difference between the novice and expert golfers was found.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	6.41	2.04	3.11	4.36	2.45	3.39	4.3	4.06	4.2	7.06	8.47	4.45	2.66	2.16	3.58	3.42	3.55	4.9	8.63	3.15	3.71	6.41	4.09	4.07	8.14
Decrease	-0.25	-0.04	-0.03	-0.95	-3.11	-0.95	-0.83	-2.41	-0.18	-0.4	-0.65	-2.67	-1.31	-1.81	-1.2	-2.16	-0.6	-1.07	-0.54	-2.66	-1.61	-0.27	-0.48	-0.9	-0.26

Figure 34. Individual measurement change at the left side length (LS) in golf swing

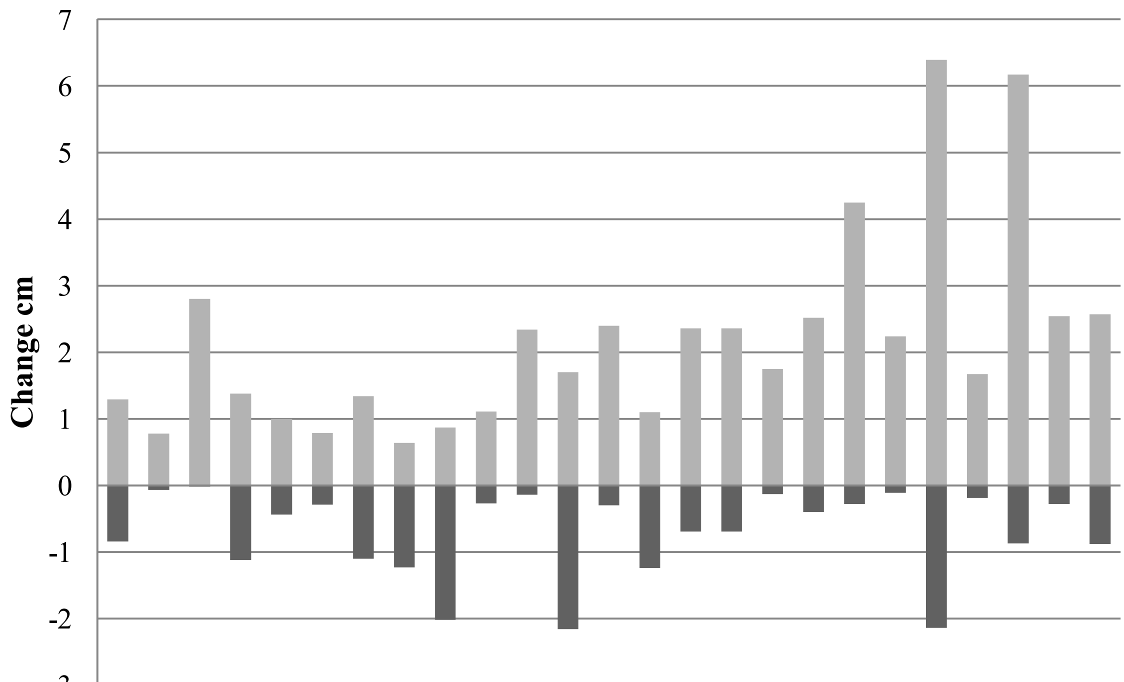
Center back length (CB). Figure 35 shows the variation f the maximum increase and maximum decrease values in the center back length (CB) for the 25 participants during the golf swing. The center back length increased from 1.03 cm to 10.44 cm, and decreased from -0.11 cm to -5.68 cm. The maximum increase values of the expert golfers were higher than the novices'.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	1.97	3.94	3.24	3.88	5.13	4.22	7.66	1.03	3.39	5.1	2.01	3.6	1.43	4.48	2.84	4.12	3.18	1.35	7.95	6.72	6.15	6	10.44	9.69	3.29
Decrease	-1.52	-0.5	-1.02	-2.5	-1.13	-2.09	-2.36	-1.42	-0.28	-1.39	-3.33	-2.08	-0.82	-1.35	-2.71	-2.64	-2.25	-3.66	-0.11	-0.5	-3.41	-1.45	-1.76	-0.54	-5.68

Figure 35. Individual measurement change at the center back length (CB) in golf swing

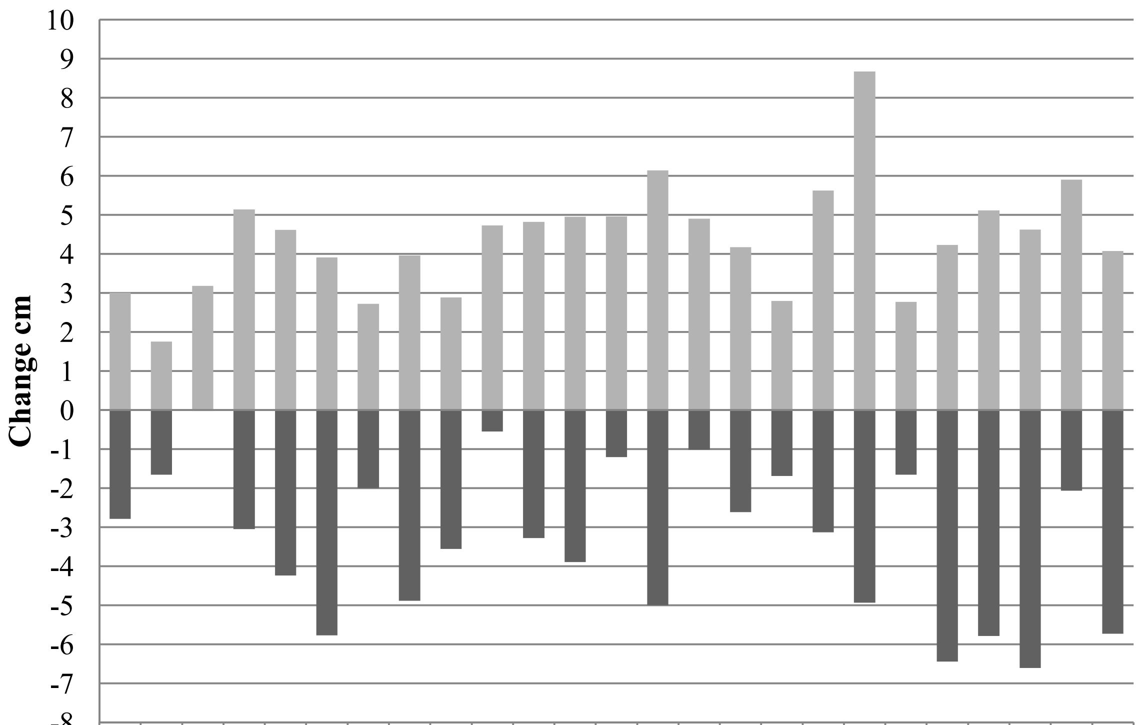
Right side length (RS). Figure 36 shows the variation of the maximum increase and maximum decrease values in the right side length (RS) for the 25 participants during the golf swing. The right side length increased from 0.64 cm to 6.39 cm, and decreased from -0.02 cm to -2.16cm. The increases are higher than the decreases, except for N8, N9, and N12. Expert golfers, P2 and P4 showed the highest maximum increase.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	1.29	0.78	2.8	1.38	1	0.79	1.34	0.64	0.87	1.11	2.34	1.7	2.4	1.1	2.36	2.36	1.75	2.52	4.25	2.24	6.39	1.67	6.17	2.54	2.57
Decrease	-0.84	-0.07	-0.02	-1.12	-0.44	-0.29	-1.1	-1.23	-2.02	-0.27	-0.14	-2.16	-0.3	-1.24	-0.69	-0.69	-0.13	-0.4	-0.28	-0.11	-2.14	-0.19	-0.87	-0.28	-0.88

Figure 36. Individual measurement change at the right side length (RS) in golf swing

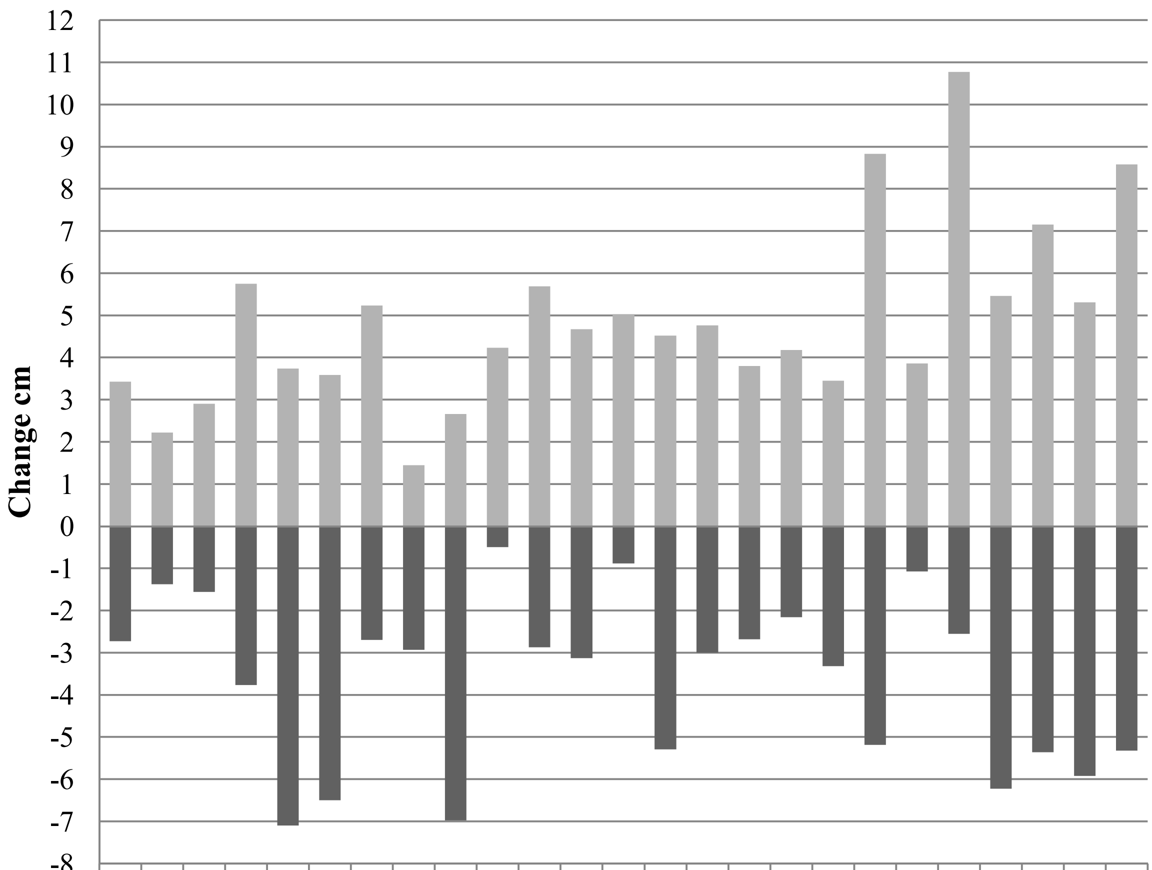
Right diagonal (RD). Figure 37 shows the variation of the maximum increase and maximum decrease values in the right diagonal (RD) for the 25 participants during the golf swing. The right diagonal increased from 1.75 cm to 8.67 cm, and decreased from -0.03 cm to -6.61 cm. Mostly, the increases were higher than the decrease, but variability of the changes in the maximum increase and decreases because of a unique golf swing among participants.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	3.01	1.75	3.18	5.14	4.61	3.91	2.72	3.96	2.88	4.73	4.82	4.95	4.96	6.14	4.9	4.17	2.79	5.62	8.67	2.77	4.23	5.11	4.62	5.9	4.07
Decrease	-2.79	-1.66	-0.03	-3.05	-4.24	-5.77	-2	-4.89	-3.56	-0.55	-3.28	-3.9	-1.21	-5	-1.02	-2.62	-1.69	-3.13	-4.94	-1.66	-6.45	-5.79	-6.61	-2.07	-5.73

Figure 37. Individual measurement change at the right diagonal (RD) in golf swing

Left diagonal (LD). Figure 38 shows the variation of the maximum increase and maximum decrease values in the left diagonal (LD) for the 25 participants during the golf swing. The left diagonal increased from 1.45 cm to 10.77 cm, and decreased from -0.5 cm to -7.1 cm. The change in the left diagonal varied due to the individuals' swing pose; thus, this measurement showed more variability among participants in comparison to other measurements.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	P1	P2	P3	P4	P5	P6
Increase	3.43	2.22	2.9	5.75	3.74	3.59	5.23	1.45	2.66	4.23	5.69	4.67	5.03	4.52	4.76	3.8	4.18	3.45	8.83	3.86	10.77	5.46	7.15	5.31	8.58
Decrease	-2.73	-1.38	-1.56	-3.77	-7.1	-6.5	-2.7	-2.93	-6.98	-0.5	-2.87	-3.13	-0.88	-5.29	-3	-2.68	-2.16	-3.32	-5.19	-1.07	-2.55	-6.23	-5.36	-5.92	-5.32

Figure 38. Individual measurement change at the left diagonal (LD) in golf swing

Mean measurement changes in golf swing. The mean measurement changes and mean percent changes are presented in Table 10 and Figure 39. The measurements increased from .88cm to 7.39cm (2.19% to 20.65%), and decreased from -5.84cm to -0.61cm (-14.47% to -2.16%). The shoulder width (S), back width (B), back arc at the armpit (BA), left side length (LS) right side length (RS) showed the greatest changes in dimensions during the golf swing test. During the golf swing, the values of the dimension increases were higher than the decreases, except for the shoulder width (S). The measurements at the armpit (BA) showed the greatest increase during the golf swing test (7.39cm, 20.65%) while the shoulder width (S) showed the greatest decrease (-5.84cm, -14.47%).

Table 10. Mean measurement changes (cm) and percent changes (%) in golf swing

Length	Measurement changes (cm)				Percent change (%)			
	Increase		Decrease		Increase		Decrease	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder width (S)	.88	.95	-5.84	2.67	2.19	2.38	-14.47	6.58
Back width (B)	5.91	1.51	-1.26	1.27	15.58	4.11	-3.34	3.47
back arc at the armpit (BA)	7.39	2.11	-1.11	1.21	20.65	6.14	-7.42	5.91
Lower back arc (LB)	3.56	2.69	-.81	1.10	11.45	8.30	-2.6	3.68
Waist (W)	1.46	1.26	-.61	.42	5.3	4.52	-2.16	1.46
Left side length (LS)	4.51	.1.92	-1.09	.91	13.19	5.47	-3.21	2.73
Center back length (CB)	2.17	1.49	-.71	.65	6.06	4.25	-1.95	1.75
Right side length (RS)	4.51	2.49	-1.82	1.33	13.29	7.38	-5.33	3.88
Right diagonal (RD)	4.38	1.43	-3.35	1.92	8.61	2.65	-3.12	4.52
Left diagonal (LD)	4.85	2.13	-3.64	1.99	9.52	4.04	-7.15	3.92

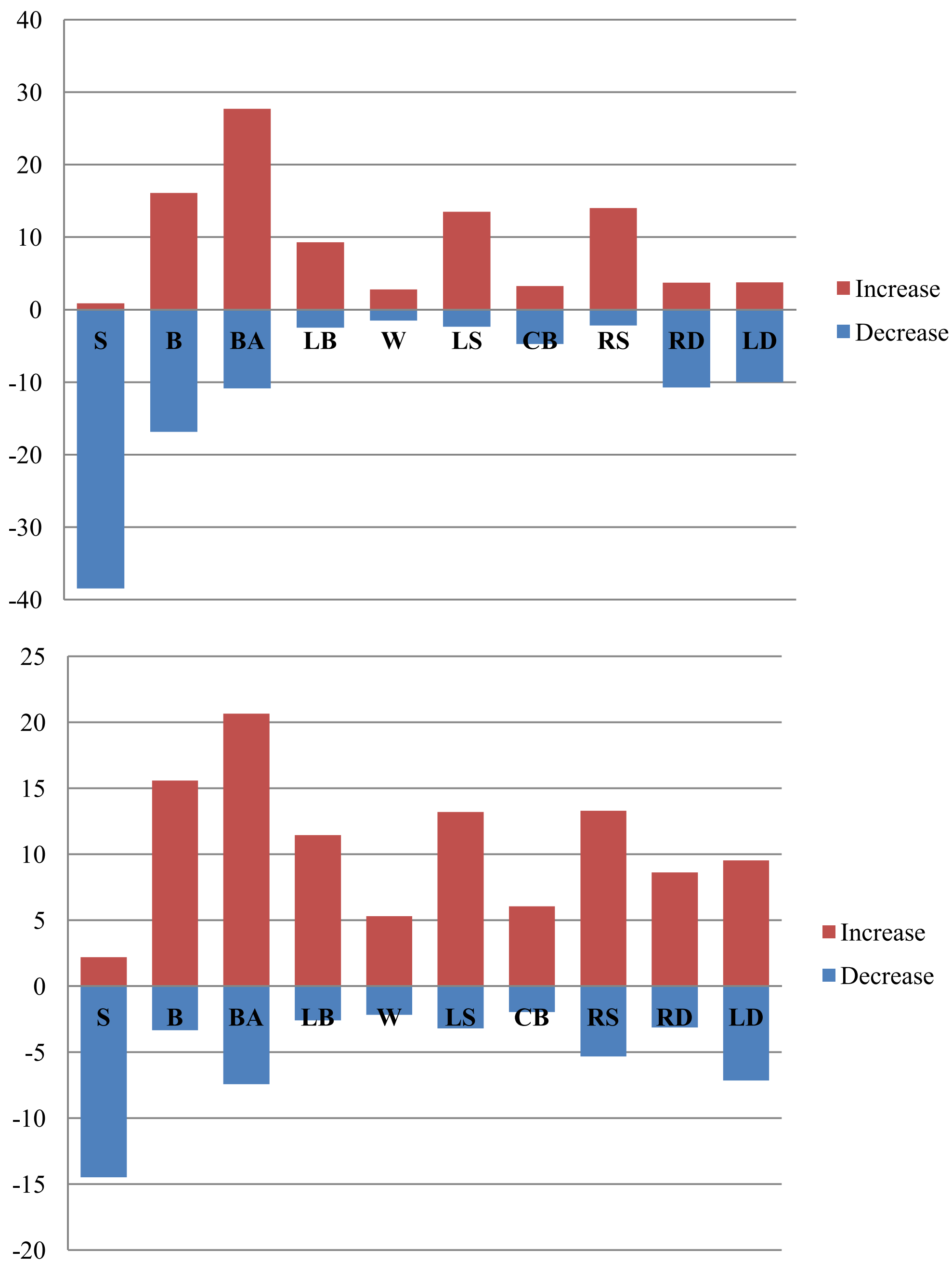


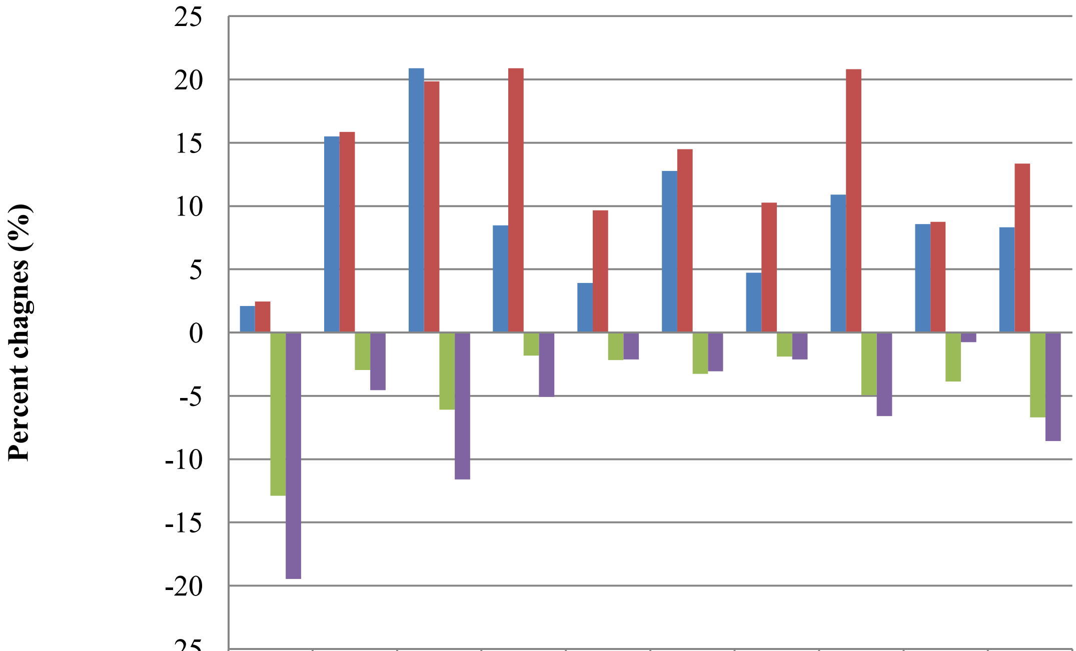
Figure 39. Mean percent change (%) in arm rotation (up) and in golf swing (down)

Comparison of mean changes between novice and expert golfers. An independent t-test was conducted to test whether there was a difference in measurements between the novices and expert golfers. The assumption of homogeneity of variance was assessed by examining Levene's test. The assumption was met because all the p-values on the maximum increase and minimum decrease of the ten measurements were more than .05. Normality of the residual was checked by the histogram, and the shape of the histograms was close to the normal. The significance was measured at the alpha <.05 level. The results of the independent t-test are listed in Table 11. The difference in the percent changes between the novice and expert golfers is presented in a graph format (see Figure 40). Analysis of the differences between the measurement changes for this study using the independent t-test revealed a significant difference in the decrease of the shoulder width (S) and increase in the lower back arc (LB), right side length (RS), and left diagonal (LD).

The measurement changes during the golf swing test were different between the novice and expert golfers due to their golf swing poses; the expert golfers' range of motion for the golf swing was larger than the novices'. Thus, the experts' measurement changes at the lower back arc (LB), right side length (RS), and left diagonal (LD) were greater than the novice's. The measurement that increased the most in the novice golf swing tests was the back arc at the armpit level (BA) (7.44 cm, 20.9%), but the values that increased the most for the experts' tests were the lower back arc (LB) (6.65cm, 20.89%) and the right side length (RS) (7.05cm, 20.82%). This suggests that golf wear for more advanced golfers may require more length overall and more width at the lower torso.

Table 11. Mean measurement changes (cm) and percent changes (%) between novice and expert golfers

Length	Measurement Change		Novice(19)		Expert (6)		t	p-value
			Mean	SD	Mean	SD		
Shoulder width (S)	Increase	cm	.85	.96	.97	.99	-.27	.79
		%	2.11	2.39	2.45	2.54	-.30	.77
	Decrease	cm	**-5.21**	2.26	**-7.83**	3.08	2.27	**.03**
		%	**-12.89**	5.67	**-19.48**	7.25	2.33	**.03**
Back width (B)	Increase	cm	5.87	1.53	6.01	1.59	-.19	.85
		%	15.5	4.12	15.85	4.44	-.18	.86
	Decrease	cm	-1.20	1.12	-1.75	1.46	1.06	.30
		%	-2.96	3.40	-4.55	3.73	.98	.34
Back arc at the armpit (BA)	Increase	cm	7.44	2.04	7.26	2.50	.17	.87
		%	20.9	5.94	19.84	7.28	.36	.72
	Decrease	cm	-1.14	1.00	-1.41	1.52	.69	.50
		%	**-6.09**	5.74	**-11.61**	4.57	2.14	**.04**
Lower back arc (LB)	Increase	cm	**2.59**	1.65	**6.65**	3.15	**-3.14**	**.02**
		%	**8.47**	5.40	**20.89**	9.21	**-4.13**	**.00**
	Decrease	cm	-.66	.52	-1.57	1.87	1.29	.25
		%	-1.82	2.06	-5.08	6.32	1.24	.27
Waist (W)	Increase	cm	1.12	.57	2.69	2.00	-1.96	.11
		%	3.93	2.17	9.67	7.13	-1.95	.11
	Decrease	cm	-.75	.68	-.56	.34	-.28	.78
		%	-2.18	1.51	-2.11	1.39	-.10	.92
Left side length (LS)	Increase	cm	4.38	1.95	4.93	1.93	-.60	.55
		%	12.78	5.47	14.5	5.79	-.66	.51
	Decrease	cm	-1.11	.92	-1.08	.95	-.18	.86
		%	-3.26	2.76	-3.05	2.90	-.16	.87
Center back length (CB)	Increase	cm	1.73	.92	3.60	2.10	-2.12	.08
		%	4.73	2.35	10.28	6.21	-2.14	.08
	Decrease	cm	-.71	.63	-.75	.76	.15	.89
		%	-1.9	1.68	-2.11	2.14	.25	.80
Right side length (RS)	Increase	cm	**3.71**	1.88	**7.05**	2.63	-3.44	**.002**
		%	**10.91**	5.69	**20.82**	7.42	-3.47	**.002**
	Decrease	cm	-1.75	.99	-2.22	1.99	.85	.41
		%	-4.93	3.13	-6.61	5.86	.92	.37
Right diagonal (RD)	Increase	cm	4.36	1.55	4.45	1.06	-.13	.90
		%	8.57	2.88	8.75	1.98	-.15	.88
	Decrease	cm	**-2.91**	1.64	**-4.72**	2.24	2.16	**.04**
		%	-3.87	3.91	-0.76	5.85	-1.51	.15
Left diagonal (LD)	Increase	cm	**4.22**	1.60	**6.86**	2.52	-3.07	**.005**
		%	**8.31**	2.98	**13.34**	4.84	-3.10	**.005**
	Decrease	cm	-3.40	1.96	-4.41	2.09	1.08	.29
		%	-6.71	3.89	-8.56	4.03	1.01	.32



	S	B	BA	LB	W	LS	CB	RS	RD	LD
NoviceIncrease	2.11	15.5	20.9	8.47	3.93	12.78	4.73	10.91	8.57	8.31
Expert Increase	2.45	15.85	19.84	20.89	9.67	14.5	10.28	20.82	8.75	13.34
Novice Decrease	-12.89	-2.96	-6.09	-1.82	-2.18	-3.26	-1.9	-4.93	-3.87	-6.71
Expert Decrease	-19.48	-4.55	-11.61	-5.08	-2.11	-3.05	-2.11	-6.61	-0.76	-8.56

Figure 40. Difference in percent change (%) between novice and expert golfers

Mean comparison between body sizes. The difference between the mean changes among body sizes was examined in the novice and expert golfers. The mean body measurements of the novice and expert golfers in a size group are presented in Table 12 and 13. Of the 19 novice golfers, six participants were size small. Five participants were size medium. Five participants were size large. Four participants were size extra large. Of the six expert golfers, one participant was size small. Two participants were size medium. Three participants were size large.

Table 12. Mean body measurements of novice golfers across sizes

	Size S (5)		Size M (5)		Size L (5)		Size XL (4)		Total (19)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bust circumference	**81.04**	3.52	**89.56**	1.55	**94.94**	1.64	**109.90**	8.49	**92.02**	11.11
Waist circumference	**64.86**	1.91	**74.02**	4.30	**79.94**	8.11	**93.00**	11.53	**77.16**	12.01
Shoulder	**38.39**	2.40	**40.97**	.84	**41.77**	2.01	**41.43**	2.60	**40.60**	2.32

width (S)										
Back width (B)	**35.25**	1.31	**38.45**	1.64	**38.03**	1.58	**40.39**	.99	**37.91**	2.26
Back arc at the armpit (BA)	**32.63**	1.11	**36.40**	1.21	**35.34**	1.08	**38.90**	1.94	**35.65**	2.56
Lower back arc (LB)	**27.76**	1.86	**30.38**	1.30	**30.87**	.78	**35.14**	1.73	**30.82**	2.93
Waist (W)	**24.22**	1.89	**27.16**	.49	**27.35**	1.18	**32.24**	1.64	**27.50**	3.10
Left side length (LS)	**32.73**	1.31	**34.19**	2.44	**34.54**	1.19	**35.12**	1.69	**34.09**	1.82
Center back length (CB)	**34.87**	1.97	**36.09**	2.73	**36.29**	1.78	**37.67**	1.63	**36.15**	2.15
Right side length (RS)	**33.09**	2.39	**33.91**	1.95	**35.39**	.98	**35.00**	.64	**34.31**	1.81
Right diagonal (RD)	**48.20**	1.78	**51.01**	3.18	**51.05**	1.36	**53.29**	.90	**50.76**	2.60
Left diagonal (LD)	**48.19**	1.04	**51.12**	2.84	**50.79**	1.19	**53.26**	1.63	**50.71**	2.46

Table 13. Mean body measurements of expert golfers across sizes

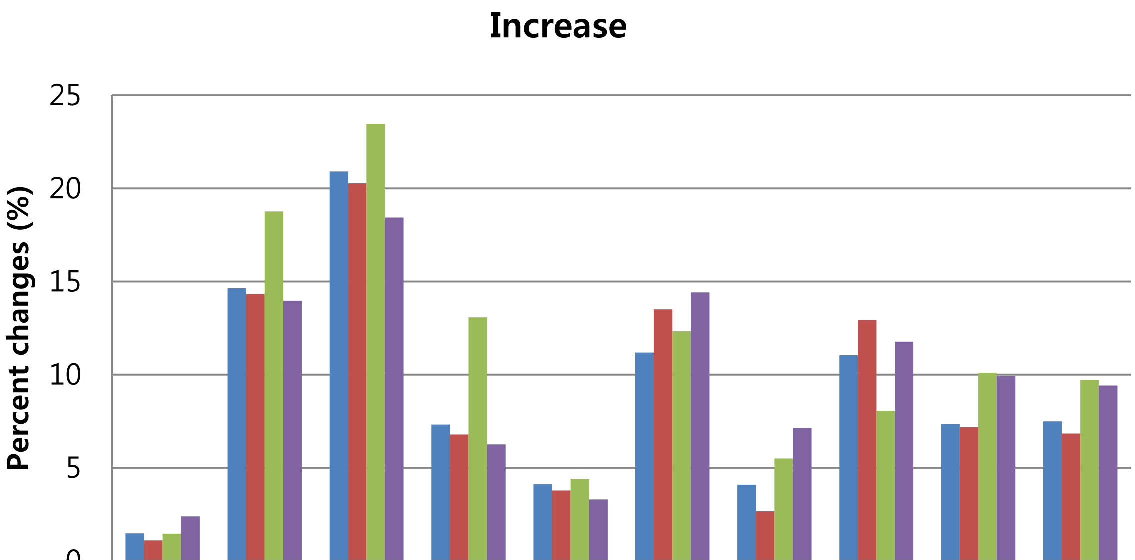
	Size S (1)	Size M (2)		Size L (3)		Total (6)	
		Mean	SD	Mean	SD	Mean	SD
Bust circumference	**80.10**	**91.35**	1.63	**95.53**	2.01	**91.57**	6.16
Waist circumference	**69.00**	**75.20**	1.84	**75.37**	4.03	**74.25**	3.71
Shoulder width (S)	**39.26**	**40.64**	.78	**39.69**	.58	**39.94**	.76
Back width (B)	**37.85**	**38.67**	.39	**37.74**	1.26	**38.07**	.94
Back arc at the armpit (BA)	**35.18**	**37.90**	.62	**36.59**	1.41	**36.79**	1.38
Lower back arc (LB)	**29.65**	**32.93**	.81	**31.47**	2.20	**31.65**	1.88
Waist (W)	**24.67**	**28.36**	.16	**27.68**	2.04	**27.40**	1.89
Left side length (LS)	**32.60**	**33.94**	.35	**34.63**	2.07	**34.06**	1.54
Center back length (CB)	**33.70**	**36.06**	.34	**35.37**	2.10	**35.32**	1.59
Right side length (RS)	**33.15**	**32.53**	.10	**34.77**	1.28	**33.75**	1.40
Right diagonal (RD)	**48.20**	**51.77**	.54	**50.80**	.19	**50.69**	1.34
Left diagonal (LD)	**49.90**	**52.18**	.25	**51.20**	.76	**51.31**	.97

The results of the descriptive statistics showed the differences in the back arc at the armpit (BA), left side length (LS), center back length (CB), right diagonal (RD), and left diagonal (LD) of the novice golfers across sizes (see Table 14 & Figure 41). The measurement in the back arc at the armpit level represented the difference of the decrease values across sizes. As the body sizes got larger, the decrease values were larger; the decrease value in the back arc at the armpit level (BA) in size small was -.38 cm (-3.95%), in size medium -.58 cm (-4.78%), in size large -1.69 cm (-7.52%), and in size xlarge -1.49 cm (-8.62%).

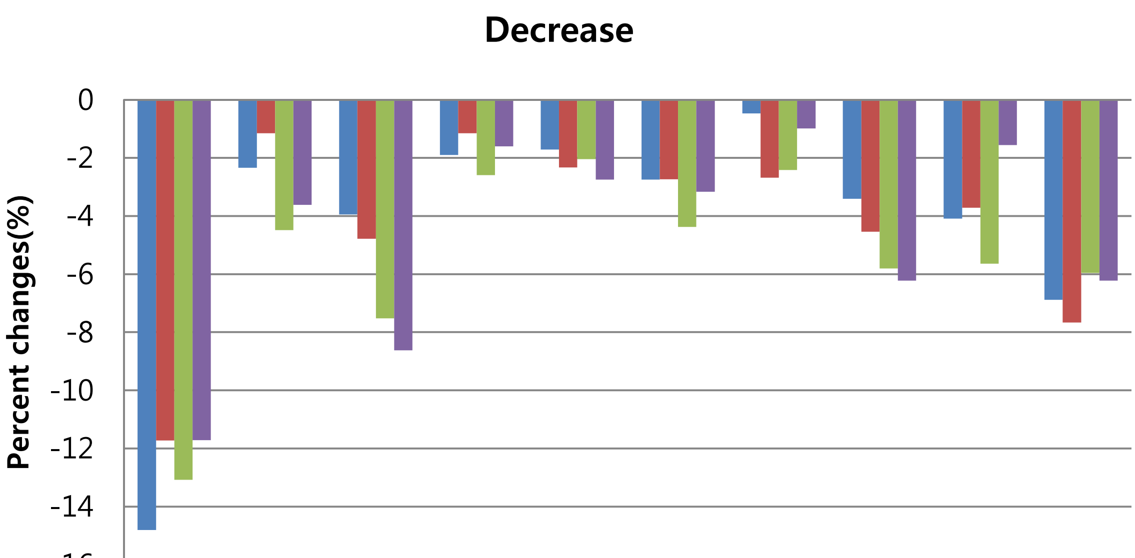
The difference in the increase values was found at the left side length (LS), center back length (CB), right diagonal (RD), and left side length (LD) across sizes. Although the increase values in the left side length (LS), center back length (CB), right diagonal (RD), and left side length (LD) did not consistently increase across sizes, the values in size large and xlarge were likely to be larger than in size small and medium. The increase values in the left side length (LS) showed that the vales in size medium and large were similar: size medium (4.60cm, 13.51%) and size large (4.26cm, 12.34%). However, the increase value in size small was 3.67cm (11.19%) and the increase value in size xlarge was 5.13 cm (14.41%). The increase values in the center back length (CB) showed that the value in size small (1.45cm, 4.08%) was larger than the value in size medium (.95cm, 2.66%), but the value in size large was 1.98 cm (5.50%) and the value in size xlarge was 2.72cm (7.15%). The increase values of the right diagonal (RD) in size small (3.54cm, 7.35%) and medium (3.64cm, 7.17%) were smaller than the values in size large (5.15cm, 10.10%) and xlarge (5.31cm, 9.92%). The increase values of the left diagonal (LD) in size small (3.61cm, 7.48%) and medium (3.43cm, 6.84%) were smaller than the values in size large (4.93cm, 1.09%) and xlarge (5.07cm, 9.41%).

Table 14. Mean measurement changes (cm) and percent changes (%) of novice golfer across sizes

	Measurement Change		Size S (5)		Size M (5)		Size L (5)		Size XL (4)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shoulder width (S)	Increase	cm	.57	.45	.45	.24	1.45	1.49	.96	1.08
		%	1.48	1.13	1.10	.59	3.52	3.73	2.39	2.80
	Decrease	cm	-5.63	2.75	-4.82	2.47	-5.44	2.26	-4.89	2.22
		%	-14.80	7.32	-11.72	5.86	-13.08	5.62	-11.71	4.86
Back width (B)	Increase	cm	5.17	2.21	5.49	.43	7.14	1.31	5.65	1.08
		%	14.63	6.37	14.32	1.39	18.77	3.41	13.96	2.33
	Decrease	cm	-.81	1.85	-.58	.48	-1.67	1.28	-1.46	.68
		%	-2.34	5.42	-1.15	1.18	-4.49	3.55	-3.62	1.74
Back arc at the armpit (BA)	Increase	cm	6.82	3.18	7.35	.96	8.30	1.57	7.24	2.27
		%	20.92.	9.84	20.27	3.22	23.47	4.39	18.44	4.84
	Decrease	cm	**-.38**	1.22	**-.58**	.18	**-1.69**	1.22	**-1.49**	1.29
		%	**-3.95**	6.99	**-4.78**	7.31	**-7.52**	5.02	**-8.62**	2.30
Lower back arc (LB)	Increase	cm	1.97	1.42	2.05	.53	4.05	2.39	2.22	.89
		%	7.31	5.44	6.79	1.88	13.07	7.61	6.25	2.25
	Decrease	cm	-.57	1.15	-.35	.18	-.79	.41	-.56	.29
		%	-1.90	3.88	-1.15	.54	-2.59	1.38	-1.61	.87
Waist (W)	Increase	cm	.99	.54	1.03	.96	1.20	.27	1.04	.53
		%	4.12	2.15	3.78	3.53	4.39	1.00	3.29	1.79
	Decrease	cm	-.44	.46	-.63	.34	-.56	.35	-.91	.67
		%	-1.71	1.85	-2.33	1.23	-2.05	1.33	-2.75	1.98
Left side length (LS)	Increase	cm	**3.67**	1.76	**4.60**	1.42	**4.26**	2.51	**5.13**	2.43
		%	**11.19**	5.29	**13.51**	4.30	**12.34**	7.32	**14.41**	6.09
	Decrease	cm	-.86	1.32	-.95	.87	-1.53	.76	-1.09	.75
		%	-2.75	4.32	-2.74	2.30	-4.38	2.02	-3.17	2.28
Center back length (CB)	Increase	cm	**1.45**	.79	**.95**	.28	**1.98**	.57	**2.72**	1.07
		%	**4.08**	1.98	**2.66**	.89	**5.50**	1.73	**7.15**	2.52
	Decrease	cm	-.47	.51	-.98	.73	-.91	.82	-.38	.24
		%	-1.34	1.44	-2.68	1.91	-2.42	2.07	-.99	.62
Right side length (RS)	Increase	cm	3.63	1.15	4.28	2.42	2.87	1.22	4.15	2.78
		%	11.05	3.91	12.93	7.71	8.06	3.29	11.77	7.66
	Decrease	cm	-1.13	1.08	-1.51	.81	-2.06	1.01	-2.17	1.49
		%	-3.41	3.10	-4.54	2.55	-5.81	2.88	-6.23	4.30
Right diagonal (RD)	Increase	cm	**3.54**	1.35	**3.64**	.83	**5.15**	.55	**5.31**	2.51
		%	**7.35**	2.87	**7.17**	1.77	**10.10**	1.14	**9.92**	4.56
	Decrease	cm	-2.35	1.59	-3.35	2.12	-2.88	1.73	-3.10	1.37
		%	-4.09	3.69	-3.72	4.39	-5.64	3.42	-1.56	4.43
Left diagonal (LD)	Increase	cm	**3.61**	1.33	**3.43**	1.45	**4.93**	.46	**5.07**	2.53
		%	**7.48**	2.72	**6.84**	3.15	**9.73**	1.09	**9.41**	4.34
	Decrease	cm	-3.31	2.33	-3.92	2.75	-3.03	1.56	-3.34	1.32
		%	-6.89	4.93	-7.67	5.35	-5.96	3.02	-6.23	2.27



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	1.48	14.63	20.92	7.31	4.12	11.19	4.08	11.05	7.35	7.48
M	1.1	14.32	20.27	6.79	3.78	13.51	2.66	12.93	7.17	6.84
L	1.45	18.77	23.47	13.07	4.39	12.34	5.5	8.06	10.1	9.73
XL	2.39	13.96	18.44	6.25	3.29	14.41	7.15	11.77	9.92	9.41



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	-14.8	-2.34	-3.95	-1.9	-1.71	-2.75	-0.47	-3.41	-4.09	-6.89
M	-11.72	-1.15	-4.78	-1.15	-2.33	-2.74	-2.68	-4.54	-3.72	-7.67
L	-13.08	-4.49	-7.52	-2.59	-2.05	-4.38	-2.42	-5.81	-5.64	-5.96
XL	-11.71	-3.62	-8.62	-1.61	-2.75	-3.17	-0.99	-6.23	-1.56	-6.23

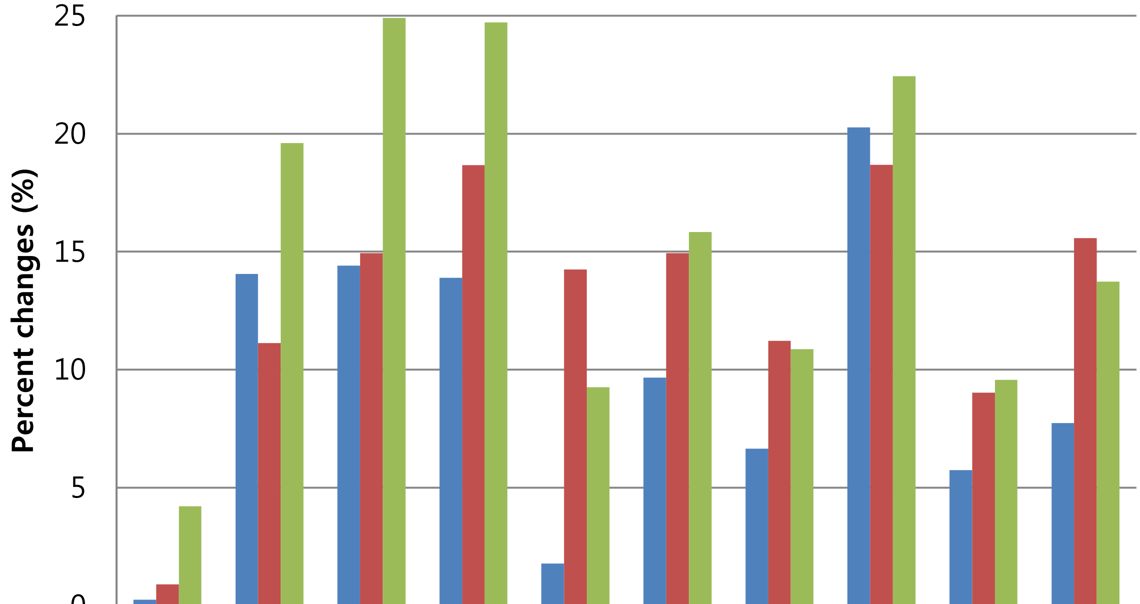
Figure 41. Percent changes (%) of novice golfers across sizes

The results of the descriptive statistics showed the differences in the back arc at the armpit level (BA), lower back arc (LB), left side length (LS), center back length (CB), right diagonal (RD), and left diagonal (LD) of the expert golfers, which was the same results with the novices' (see Table 15 & Figure 42). The results indicated that the measurement changes increased as the body size got larger. The increase value of the back arc at the armpit level (BA) in size small was 5.07cm (14.41%), in size medium 5.68cm (14.94%), and in size large 9.05cm (24.91%). The decrease value of the back arc at the armpit level (BA) in size small was -1.17(-3.33%), in size medium -2.55cm (-12.08%), and in size large -.74cm (-14.06%). The increase value of the lower back arc (LB) in size small was 4.12cm (13.90%), in size medium 6.10cm (18.66%), and in size large 7.87cm (24.71%). The increase value of the left side length (LS) in size small was 3.15cm (9.66%), in size medium 5.06cm (14.94%), and in size large 5.43cm (15.83%). The increase value of the center back length (CB) in size small was 2.24 cm (6.65%), in size medium 4.03cm (11.22%), in size large 3.76cm (10.87%). The increase value of the right diagonal (RD) in size small was 2.77cm (5.75%), in size medium 4.67cm (9.03%), and in size large 4.86cm (9.57%). The increase value of the left diagonal (LD) in size small was 3.86 cm (7.74%), in size medium 3.75cm (7.27%), and in size large 7.01cm (13.73%). The decrease value of the left diagonal (LD) in size small was -1.07 cm (-2.14%), in size medium -4.39cm (-8.40%), and in size large -5.53cm (-10.80%).

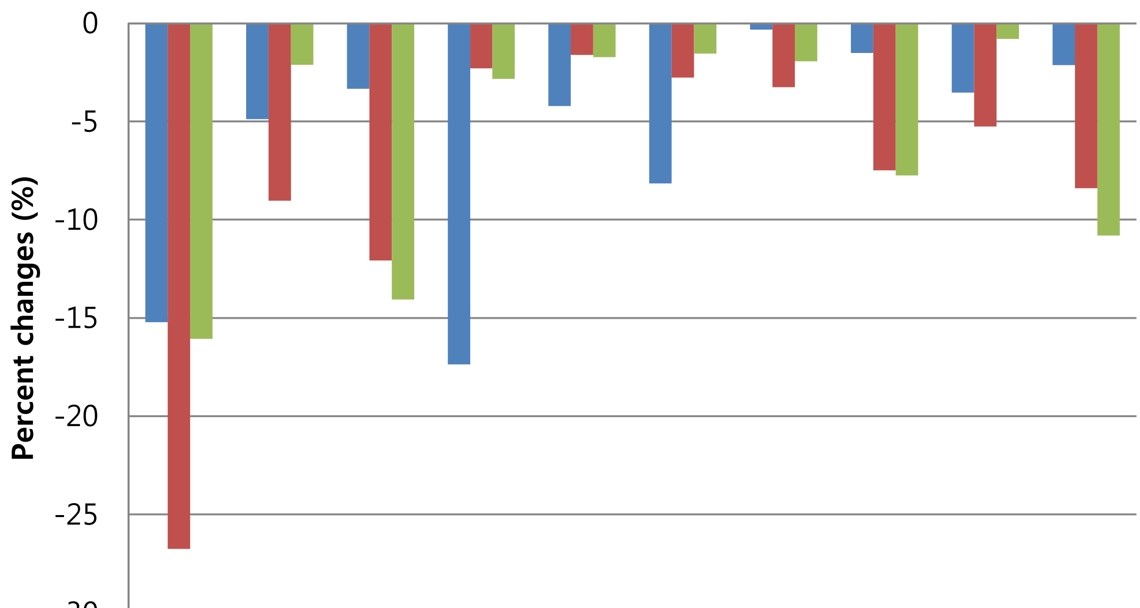
The results of the measurement changes of the novice and expert golfers showed that there was a difference in the back arc at the armpit level (BA), left side length (LS), center back length (CB), right diagonal (RD), and left diagonal (LD) among size groups. Overall, as body sizes got larger, the percent changes (%) increased.

Table 15. Mean measurement changes (cm) and percent changes (%) of expert golfers across sizes

Length	Measurement Change		Size S (1)	Size M (2)		Size L (3)	
				Mean	SD	Mean	SD
Shoulder width (S)	Increase	cm	.10	.37	.04	1.66	1.01
		%	.25	.90	.10	4.21	2.60
	Decrease	cm	-5.97	-10.91	3.61	-6.39	1.71
		%	-15.21	-26.75	8.38	-16.06	4.07
Back width (B)	Increase	cm	5.32	4.31	.050	7.38	.58
		%	14.06	11.13	.02	19.60	2.11
	Decrease	cm	-1.85	-3.12	2.01	-.79	-1.75
		%	-4.89	-8.04	5.11	-2.12	.81
Back arc at the armpit (BA)	Increase	cm	**5.07**	**5.68**	1.83	**9.05**	2.04
		%	**14.41**	**14.94**	4.59	**24.91**	6.70
	Decrease	cm	**-1.17**	**-2.55**	2.52	**-.74**	.78
		%	**-3.33**	**-12.08**	.74	**-14.06**	2.91
Lower back arc (LB)	Increase	cm	**4.12**	**6.10**	4.04	**7.87**	3.30
		%	**13.90**	**18.66**	12.72	**24.71**	8.93
	Decrease	cm	-5.15	-.76	.16	-.92	1.02
		%	-17.37	-2.30	.42	-2.84	3.02
Waist (W)	Increase	cm	.44	4.03	2.84	2.55	1.28
		%	1.78	14.24	10.11	9.25	4.86
	Decrease	cm	-1.04	-.46	.16	-.47	.37
		%	-4.22	-1.62	.56	-1.73	1.41
Left side length (LS)	Increase	cm	**3.15**	**5.06**	1.91	**5.43**	2.34
		%	**9.66**	**14.94**	5.78	**15.83**	7.25
	Decrease	cm	-2.66	-.94	.95	-.55	.33
		%	--8.16	-2.76	2.76	-1.55	-3.05
Center back length (CB)	Increase	cm	**2.24**	**4.03**	3.34	**3.76**	2.09
		%	**6.65**	**11.22**	9.36	**10.87**	6.69
	Decrease	cm	-.11	-1.17	1.38	-.68	.34
		%	-.33	-3.25	3.85	-1.94	1.04
Right side length (RS)	Increase	cm	6.72	6.08	.11	7.81	3.93
		%	20.27	18.68	.38	22.44	11.35
	Decrease	cm	-.50	-2.43	1.39	-2.66	2.69
		%	-1.51	-7.48	4.28	-7.74	7.81
Right diagonal (RD)	Increase	cm	**2.77**	**4.67**	.62	**4.86**	.94
		%	**5.75**	**9.03**	1.30	**9.57**	1.84
	Decrease	cm	-1.66	-6.12	.47	-4.80	2.41
		%	-3.53	-5.25	10.07	-.80	1.34
Left diagonal (LD)	Increase	cm	**3.86**	**8.12**	3.75	**7.01**	1.64
		%	**7.74**	**15.57**	7.27	**13.73**	3.36
	Decrease	cm	**-1.07**	**-4.39**	2.60	**-5.53**	.34
		%	**-2.14**	**-8.40**	4.95	**-10.80**	.49



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	0.25	14.06	14.41	13.9	1.78	9.66	6.65	20.27	5.75	7.74
M	0.9	11.13	14.94	18.66	14.24	14.94	11.22	18.68	9.03	15.57
L	4.21	19.6	24.91	24.71	9.25	15.83	10.87	22.44	9.57	13.73



	S	B	BA	LB	W	LS	CB	RS	RD	LD
S	-15.21	-4.89	-3.33	-17.37	-4.22	-8.16	-0.33	-1.51	-3.53	-2.14
M	-26.75	-9.04	-12.08	-2.3	-1.62	-2.76	-3.25	-7.48	-5.25	-8.4
L	-16.06	-2.12	-14.06	-2.84	-1.73	-1.55	-1.94	-7.74	-0.8	-10.8

Figure 42. Percent changes (%) of expert golfers across sizes

Summary: Results

A total of 25 women participated in this study. All of them participated in the golf swing test; six were the golf team members and 19 were novices. Of the 25 participants, 19 participated in the arm rotation test.

The motion capture system can be a reliable method to collect body measurements and to examine the body measurement changes in motion. The results of ICC tests showed that values of all ICCs were close to 1.0, indicating that there was no variance between the three repeated measurements. The results of the paired t-test are revealed a significant difference in the lower back arc (LB), waist arc (W), left side length (LS), right diagonal (RD), and left diagonal (LD) ($p<.05$). However, the difference values ranging from -.40 cm to .42cm were acceptable in this context because they were within the range of variability that can occur during the measurement process.

Descriptive analysis of the body measurement change in the two different motion tests in this study indicated that upper body measurements increased or decreased corresponding to the shoulder joint and scapula movement. The shoulder and back arc at the armpit showed the greatest measurement change. The back arc at the armpit increased the most, while the shoulder width decreased the most in the upper body during the motion that involved the arm and torso movement.

When the participants performed the arm rotation motion, the shoulder width (-38.45%), back width (16.08%), and back arc at the armpit (27.69%) showed the most change. The locations that changed measurements the most were the same as the results from the golf swing test. When the participants performed the golf swing motion, the shoulder width (-14.47%), back width (15.58%), and back arc at the armpit (20.65%) changed the most.

An independent t-test indicated that the measurement changes in the golf swing test were different between the novice and expert golfers due to their golf swing poses. There was a significant difference in the decreases of the shoulder width, and the increases of the lower back arc, right side length, and left diagonal on the back of the body.

The results of this study suggest that the measurement changes and percent changes increased as body size increased in two different motion tests. In the arm rotation motion test, the changes in the shoulder width (S), back width (B), back arc at the armpit level (BA), lower back arc (LB), left side length (LS), center back length (CB), right side length (RS), right diagonal (RD), and left diagonal (LD) increased as the body sizes got larger. In the golf swing motion test, there was a difference in the back arc at the armpit level (BA), left side length (LS), center back length (CB), right diagonal (RD), and left diagonal (LD) among size groups. Overall, as body sizes got larger, the percent changes increased.

CHAPTER FIVE: DISCUSSION AND CONCLUSION

This study explored a research method to examine the human body using a motion capture system. It tested the accuracy and reliability of the motion capture system in measuring a human body in comparison to the 3D body scanner. Using a motion capture system, this study examined the measurement changes in two motions: arm rotation and golf swing. Difference in the measurement changes among participants who have different level of expertise in golf was examined. The measurement changes in motion across body sizes were examined as well.

The exploratory research was developed based on the framework for micro and macro levels of fit (see Figure 43). In the framework for micro and macro levels of fit, measuring the body is the first step in the development of a garment pattern. Body measurement methods have been explored in an attempt to adequately characterize the three-dimensional body form. Bye et al (2006) stated that measuring the human body in motion is the next frontier of development of human body measurement for garment design. Thus, this study explored a new way to measure the human body in motion, using a motion capture system as a new body measurement tool. The study focused on individual body measurement changes in motion at the micro level and the difference of changes among body size groups at the macro level.

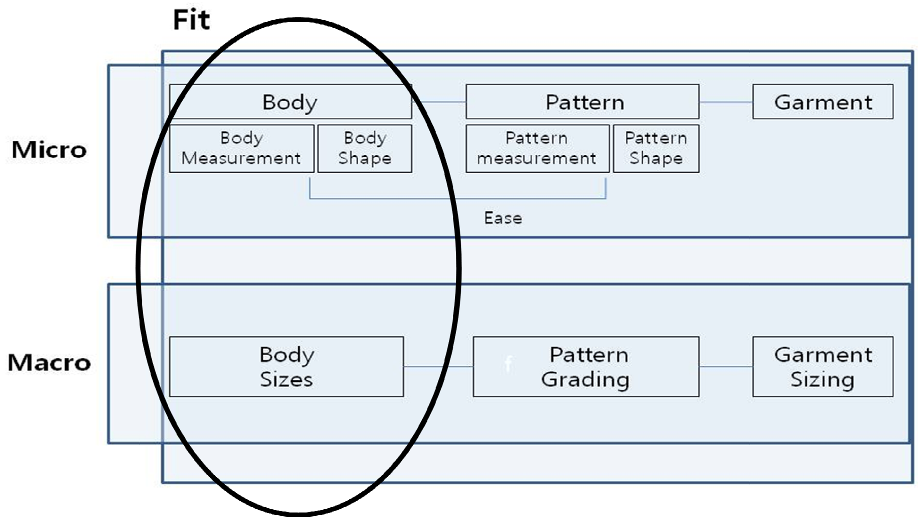


Figure 43. Conceptual framework for this study

Reliability of a Motion Capture System as a New Measurement Method

In response to the research question 1a and lb, this study suggests that the motion capture system can be successfully used as a body measurement method. Inter-rater reliability for three repeated measures from the motion capture system was tested and the motion capture measurements were compared to manual measurements from a 3D body scanner. There was no variance within the repeated measurements from the motion capture system. Also, considerable differences between the motion capture system and 3D body scanner were not found although the lower back arc, waist arc, and two diagonal lines (right shoulder tip to the left side waist and left shoulder tip to the right side waist) were slightly larger in the scanned measurements than in the motion capture measurements. However, the differences occurred at curved areas of the body. The motion capture data uses straight lines between markers, as opposed to curved lines. Thus, the measurements from the 3D body scanner, which reads the curved surface of the body, would logically be larger. Comparing two measuring methods, the difference in values ranged from -.40 cm to .42 cm, which was within the range of variability that can occur in the measurement process. The results of this study suggested that the measurements from the motion capture system were reliable. The use of repeated measures helped to improve the accuracy of the measurements. There was no substantial difference between the measurements from the motion capture system and from the 3D body scanner. However, measuring the whole body, in particular bust circumference, may be difficult due to occlusion. The information was lost when the markers were occluded by other body parts.

Body Movement and Anatomy

Anatomy is recognized as key to good pattern construction because it plays an important role in measurement (Gray, 1998). Joint movement is considered the most important factor in body movement and body measurement change analysis. When there is body movement, positions of different joints change significantly, and body skin surfaces around the joints extend and contract; thus, body skin surfaces change resulting in body measurement changes. Wang, Mok, Li, and Kwok (2009) indicated that there is an interaction between joint movement and body measurement. They found that the maximum decrease (-15.75cm) was for the horizontal shoulder width. When the scapula was elevated, shoulder width was the measurement that decreased the most. Similarly, in response to research question 2a and 2c, the results of the body measurement change in the two different motion tests in this study indicated that upper body measurements increased or decreased corresponding to the shoulder joint and scapula movement. Figure 44 shows the change values in the ten selected measurements during the arm rotation and golf swing motion tests relating to research question 2b and 2d. When the participants performed the arm rotation motion, the shoulder width, back width, and back arc at the armpit showed the most change; the shoulder width increased .34cm (.87%) and decreased -15.31cm (-38.45%), the back width increased 5.96 cm (16.08%) and decreased -6.26cm (-16.84%), and the back arc at the armpit increased 9.88cm (27.69%) and decreased -3.91cm (-10.88%). The locations that changed measurements the most were the same as the results from the golf swing test. When the participants performed the golf swing motion, the shoulder width, back width, and back arc at the armpit changed the most; the shoulder width increased .88cm

(2.19%) and decreased -5.84cm (-14.47%), the back width increased 5.91 cm (15.58%) decreased 1.51cm (-3.34%), and the back arc at the armpit increased 7.39cm (20.65%) and decreased -1.11 cm (-7.42%). In the golf swing motion, the two diagonals increased more and the shoulder width decreased more than the arm rotation motion. Although there was a little difference between the measurements from two motion tests, the shoulder and back arc at the armpit where the shoulder joint and scapula are located in showed the greatest measurement change. The back arc at the armpit increased the most, while the shoulder width decreased the most in the upper body during the motion that involved the arm and torso movement. To measure the dynamic body for apparel product development, the anatomy of body movement involved in specific activities needs to be considered as a first step.

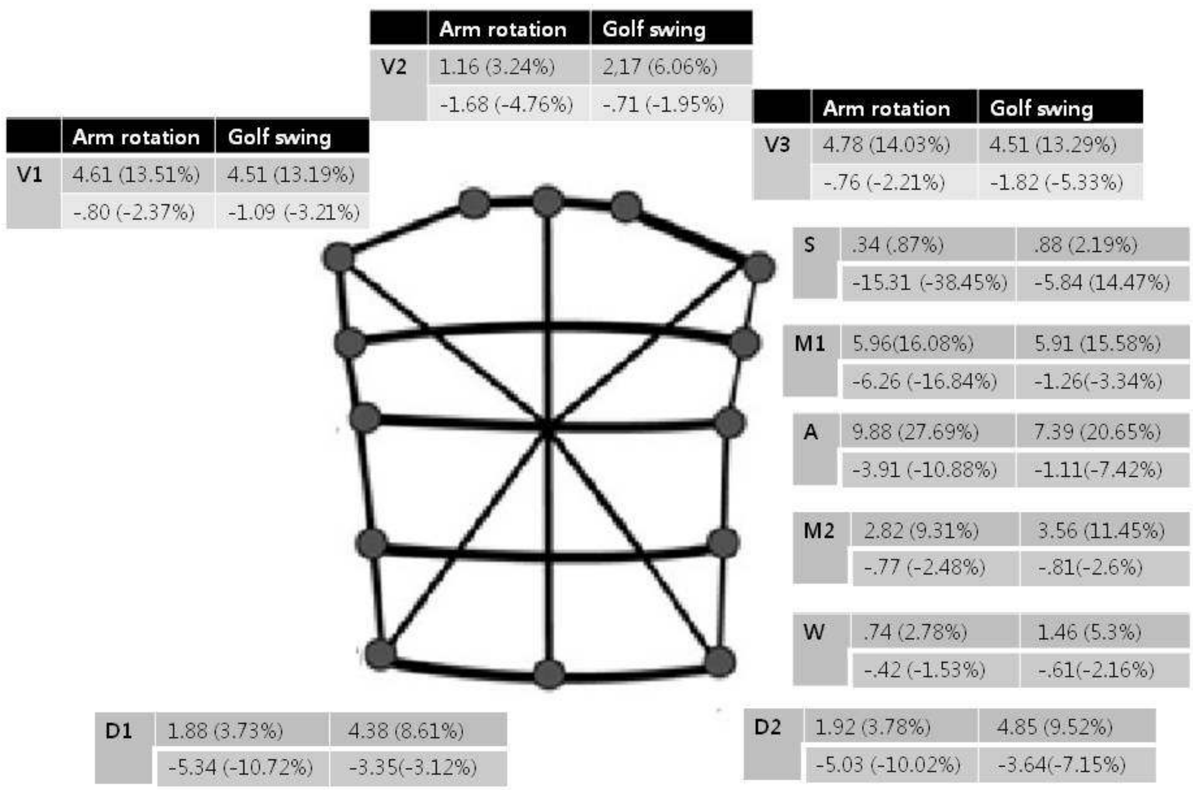


Figure. Measurement changes in arm rotation and golf swing (unit: cm)

Dynamic Anthropometry

Research on dynamic anthropometry has been considered difficult to conduct due to human variability and movement control. Dynamic movements are often subject to higher variation among individuals due to the different levels of mobility and flexibility (Gill, 2009). In order to limit the human variability, research methods have controlled the movements, thus few have focused on natural movement. However, this study tested the motion capture system's ability to measure the body in continuous movement. The results of this study indicate that the motion capture system is useful for dynamic anthropometric study, in particular studying continuous natural movement because this technology does not require measuring a variety of static postures that make up an activity. However, there are limitations in studying natural movements. In this study, the natural speed of a golf swing could not used due to limitations of the motion capture system. In addition, the discomfort caused by the markers attached on the body might affect body movement. Despite limitations, this exploratory research can provide initial insights into using motion capture technology to study human body movement in natural settings.

Advantages of the motion capture system are that it can provide information on measurement change in motion over time and the location where the measurement changes occur. With the use of the motion capture system, this study showed how the measurement changes occurred during continuous motion. The graph of measurement changes during the motion provides valuable information regarding how the measurement changes are related to each other. For example, when the shoulder was elevated, the vertical lengths increased while the horizontal widths decreased.

Another advantage of the motion capture system is that it allows the study of movement involving time, energy, and space. Although this research was concerned with space, which represents x, y, z position, all three factors may be associated with clothing design (Watkins, 1995). It is important to know the position of the arm when the person swings the club, but in some cases, such as table tennis strokes, the frequency of the movement during an actual game may be an important factor for designers to consider.

Although considerable research on human body movement has been conducted, applying data on body movement to clothing design has not been fully explored (Watkins, 1995). The method used for this study using a motion capture system provides valuable data for application to garment design because it provides maximum increases and maximum decreases of body measurements in motion while previous research provided measurement changes only in selected postures. These measurement changes can lead to an understanding of amounts of garment ease that can provide maximum comfort to individuals who have different levels of expertise in an activity and who are in different body size groups. In response to research question 3, the findings of this study showed that individuals' measurements change differently depending upon their sports expertise. The measurement changes in the golf swing test were different between the novice and expert golfers due to their golf swing poses. The expert golfers' range of motion for the golf swing was larger than the novices', and there was a significant difference in the decreases of the shoulder width, and the increases of the lower back arc, right side length, and left diagonal on the back of the body. For example, the novices' measurement changes mostly occur at the armpit level arc whereas the expert golfers' measurement changes mostly occur at the waist. The measurement that increased the most in the golf swing tests for the novices was the back arc at the armpit (20.9%), but the values that increased the most for the experts' tests were the lower back arc (20.89%) and right side length (20.82%). This suggests that sportswear designers need to consider the needs of wearers with different levels of expertise. Golf wear for more advanced golfers may require more length overall and more width at the lower torso.

In response to research question 4, the results of this study suggest that the measurement changes and percent changes increased as body size increased. In the arm rotation test, most measurements including the shoulder width, back width, back arc at the armpit, lower back arc, left side length, center back length, right side length, right diagonal, and left diagonal increased as the body sizes increased; the shoulder width, back width, and lower back arc showed a difference in the decrease values across sizes, and the back arc at the armpit, left side length, center back length, right side length, right diagonal, and left diagonal showed a difference in the increase values across sizes.

The differences of the mean changes among body sizes were examined in the novice and expert golfers in the golf swing test. The results of descriptive statistics of the novice golfers across sizes showed the difference of the change values in the back arc at the armpit, left side length, center back length, right diagonal, and left diagonal. The values of the maximum decrease in the back at the armpit were larger as the body size increased. The values of the maximum increase in the left side length, center back length, right diagonal and left diagonal increased across sizes. Likewise, descriptive statistics indicate that expert golfers across sizes showed the difference of the change values in the back arc at the armpit, lower back arc, left side length, center back length, right diagonal, and left diagonal; the maximum increase and decrease values of the back arc at the armpit, maximum increase values of the lower back arc, left side length, the center back length, right diagonal and left diagonal on the back of the body increased as the body size increased. Although the value of the changes in the novice group was different from the values in the expert group, the changes were found at the same location in both groups.

This suggests that more wearing ease is required for large size women than small size women. These findings coincide with the statement by Page (2003) that ease depends on body type; a fuller figure needs more ease than a thinner figure. Also ease is proportional to height. A taller figure can support more ease; a petite figure can be overwhelmed by loose-fitting garments. From the results of both motion tests, the growth in changes across sizes was found in the vertical lengths and diagonals and the back arc at the armpit. This suggests that wearing ease for mobility is not constant across sizes, but should increase as body size increases.

Conclusion and Implication

The results of this study suggest that a motion capture system can be a reliable method to collect body measurements and to examine the body measurement changes in motion. The motion capture system allowed considering variations in continuous movements among individuals across sizes for dynamic anthropometric studies. Despite these variations, the upper body measurement changes increased or decreased primary due to the shoulder joint and scapula movement. The shoulder and back arc at the armpit showed the greatest measurement change in two upper body motion tests. The results of this study suggest that the measurement changes and percent changes increased as body size increased. From the results of both motion tests, the growth in changes across sizes was found in the vertical lengths and diagonals and the back arc at the armpit.

This study had limitations. The participants were limited in age range, were all women, and their body shapes and postures were not considered. There were limitations of the motion capture system. In order to let the camera capture the position of the markers, the motion needed to be slowed down to 25 sec for the arm rotation and to 35 sec. for the golf swing. Thus, this study was limited to study a natural movement although it was concluded that the motion capture system can be used successfully to measure the body in continuous movement. Some markers were attached on the fabric, not on the skin, so fabric shifting could affect the measurement changes in motion. Another limitation was occlusion. When the markers were covered by other body parts, the information of the occluded marker location was lost. This led to the focus on the back of the upper body. In order to record the whole body, more cameras may be necessary.

Despite the limitations, this study is meaningful in that a new method to measure the human body was explored with a motion capture system. In the aspect of the micro level of fit, this provided valuable information regarding the measurement changes in continuous motion. This method provides measurement change in motion over time and the location where the measurement changes occur with different motions as well as how the measurement changes are related to each other.

The method used for this study using a motion capture system provides valuable data for application to garment design. Huck, Maganga, and Kim (1997) found that clothing ease can be determined by using body movement analysis. The measurement changes can apply to the garment block pattern dimensions. Gill (2011) pointed out the importance of objective data to indicate pattern dimensions, which can control the pattern with a less subjective process of construction. Garment patterns require some amount of ease allowance for good fit and styling of a garment, but there is little empirical evidence regarding the ease allowance and how they are determined. Knowing the actual changes in body measurement values can provide the ease values for improved fit. Jay (1969, p16) defined, "block pattern dimensions = body measurement + (ease allowance = function requirements + comfort requirements+ fabric characteristics + over size)." The body measurement in this sentence referred to the static body measurement. The measurement changes for the specific movement can help to determine the ease allowance for the pattern dimensions. Thus, the results of this study can be used to determine the ease amounts and their location on golf wear garment patterns. Measuring the dynamic body can help inform the development of patterns for sportswear or functional clothing by providing actual values and the percent changes of body measurements. The measurements that increase or decrease significantly in certain activities must be addressed as key areas to ensure comfort and mobility in clothing. These measurements may help in selecting stretch characteristics of the fabric to provide maximum comfort and mobility for active wear. For example, this study showed that the shoulder width decreased the most (-15.31cm, -38.45%), but increased the least (.34cm, .87%) in the arm rotation test. This suggested that minimal ease is required for the shoulder width, but fabric needs to be selected to consider the decreased amount with comfort.

The body measurement changes for specific body movements can be useful information for application to garment design. The most common way may add extra inches to either the width or length of a garment segment to allow for the change in body dimensions during movement. For example, Do (2008) developed a motorcycle jacket pattern based on measurement changes in motorcycle riding postures. The riding posture was scanned using a 3D body scanner and the measurement changes were applied to the pattern. The study suggested that the length and width of the front pattern needed to decrease 4% and 20% each, while the length and the width of the back pattern increased 6% and 18% each in comparison to the length and width of the pattern in standing posture. The method used for this study using a motion capture system can provide three-dimensional visualization of body form changes during motion (see Figure 45). Though not part of this study, the body form changes are also captured in a visual format that may be used for visual analysis for body movement in dynamic anthropometric studies and as for virtual dynamic fit evaluation.

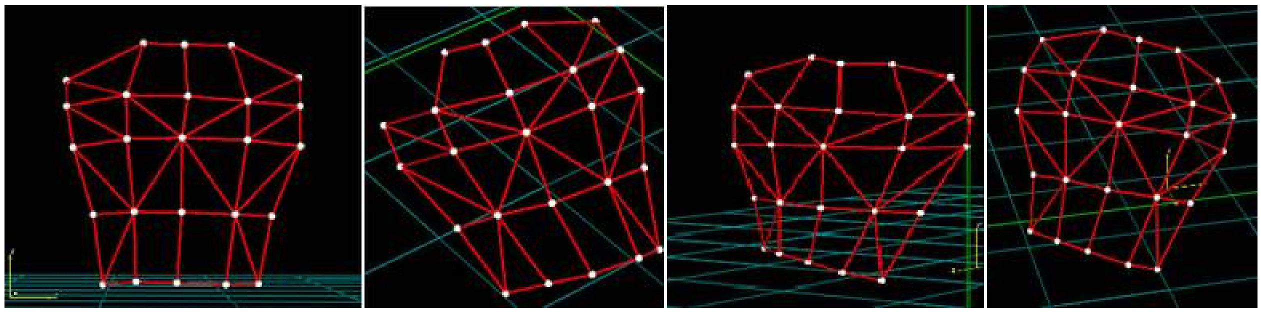


Figure 44. Three-dimensional visualization of body form changes from motion capture system

At the macro level of fit, this study showed differences in the measurement changes among different body size groups. The results suggested that wearing ease for mobility should increase as body size increases, in particular at the vertical lengths and the back arc at the armpit level. This finding was different from the result found by Petrova and Ashdown (2008). The results of their exploratory study suggested that ease allowances might decrease with increasing size. However, they tested the lower body whereas this study focused on the upper body. This would mean that wearing ease needs to be calculated differently for different body locations. Therefore, future research on the ease across sizes in different body locations is necessary with more subjects of different body sizes and/or body types.

This research method may finally provide information to designers and manufacturers on the amounts of garment ease that should be incorporated into apparel to provide for maximum wearer comfort and mobility, and is a starting point to evaluate the dynamic aspects of garment fit.

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APPENDIX A: Consent Form

Analysis of Upper Body Measurement Change using Motion Capture

You are invited to be in a research study to examine upper body measurement change using Motion Capture system. You were selected as a possible participant because you expressed an interest after learning of this study from a poster. I ask you to read this form and to ask any questions you may have before agreeing to be in the study.
This study is being conducted by:
Principal Investigator: MyungHee Sohn, a Ph.D. student at the University of Minnesota

Study Purpose:
The purpose of this study is to examine the changes in the upper body surface measurement using Motion Capture system.

Procedure:
If you agree to be in this study, I would ask you to complete a contact/personal information sheet with your name, permanent mailing address, race, and ethnicity and allow us to scan your body measurements. Once you are selected as a participant for motion capturing process, you will be asked to shecule 45-minute appointment for the motion capuring session. When you come to the lab for motion capturing process, you will be asked to perform the selected movements in Motion Capture System. The movements include trunk flexion, lateral flexion, upright trunk rotation, trunk rotation, trunk flexion and rotation, trunk hyperextension, and arm rotation in a vertical plane. The entire study can be completed in two weeks, in two approximately 30 minute sessions, including today's screening session.

Risk and Benefits of being in the Study: *There are no risks or benefits in this study.*

Study Costs/Compensation:
I will provide $15.00 to all subjects who complete both screening and motion capturing sessions.

Confidentiality:
The records of this study will be kept private. In any sort of report I might publish, I will not include any information that will make it possible to identify a subject. Research records will be stored securely and only the researcher will have access to the records.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current of future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researcher conducting this study is: MyungHee Sohn. You may ask any questions you have. If you have questions later, you are encouraged to contact us at 240 McNeal Hall, St. Paul, MN 55108, 612-624-9825, ebye@umn.edu or sohnx019@umn.edu
If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-3751.

Statement of Consent:
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.
Signature:_________________________________ Date: ________________

Signature of Investigator:________________________Date: ________________

1. How long have you played golf?
    a. Beginner
    b. 1-2 years
    c. 3-4 years
    d. 4-5 years
    e. More than 5 years

2. How often do you play golf?
    a. Once a week
    b. Once a month
    c. Once a year
    d. Golf team member