THE EFFECTS OF WEARING A COMPRESSION TOP ON GOLFERS’ TRUNK MOTION DURING GOLF SWING

So-Young Jung

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

Department of Human Environmental Studies

Central Michigan University
Mount Pleasant, Michigan
June 2013
Accepted by the Faculty of the College of Graduate Studies

Central Michigan University, in partial fulfillment of

the requirements for the master’s degree

Thesis Committee:

Carol A. Beard, Ph.D.  Committee Chair
Ksenia I. Ustinova, Ph.D.  Faculty Member
Su Kyoung An, Ph.D.  Faculty Member

June 12, 2013  Date of Defense

Roger Coles, Ed.D.  Dean
College of Graduate Studies

July 31, 2013  Approved by the
College of Graduate Studies
ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the members of my thesis committee: Dr. Carol A. Beard, Dr. Ksenia I. Ustinova, and Dr. Su Kyoung An. Their valuable guidance and experience helped to make this project more complete and better organized. I would especially like to thank Dr. Carol A. Beard for encouragement and faith in development of this thesis, and also Dr. Ksenia I. Ustinova for her countless hours to instruct a Qualisys' motion capture system and data analysis. Lastly, I am grateful for the unconditional and infinite support from my parents so that I can study abroad and develop my abilities academically and professionally.
ABSTRACT

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by So-Young Jung

An increased interest in compression garments has led to a new golf fashion trend that includes wearing a long-sleeve compression top layered with a short-sleeve t-shirt over the compression top. The purpose of this study was to investigate the effects of wearing a commercial compression top on golfers’ kinematic variables required in full swing by using a Qualisys’ motion capture system. An exploratory study was done in order to compare 11 male golfers’ trunk rotations in a transverse plane recorded during 10 full swings under two conditions: wearing a golf t-shirt with and without a compression top. The data was used to calculate rotational differences between a golfer’s shoulders and pelvis at the top of backswing (X-factor), in the downswing (peak X-factor and X-factor stretch), and peak velocity of the golf club. The results showed that the X-factor was not statistically different when wearing a compression top, and an X-factor stretch was statistically significant when wearing a compression top. Also, peak velocity of the golf club was not statistically different when wearing a compression top. Despite wearing compression tops that restricted golfers’ trunk rotational movement, the peak velocity of the golf club was slightly higher during swing. It should be noted that golfers’ performance measured by peak velocity of the club improved with wearing a compression top. The results from this study could help elite golfers and their coaches make golf apparel decisions on the basis of potential improvement in performance.
TABLE OF CONTENTS

LIST OF TABLES ............................................................................................................. vi

LIST OF FIGURES .......................................................................................................... vii

CHAPTER

I. INTRODUCTION ........................................................................................................ 1

II. LITERATURE REVIEW .............................................................................................. 4
    Compression Garments .......................................................................................... 4
    Golf ....................................................................................................................... 8
    Golf Wear .......................................................................................................... 9
    Golf Swing ..................................................................................................... 10
    Biomechanical Factors for Analysis of Golf Swing ..................................... 13
    Lower Back Pain in Golfers ........................................................................... 15

III. METHODOLOGY ...................................................................................................... 19
    Design .............................................................................................................. 19
    Subjects ........................................................................................................... 19
    Experimental Set-up ....................................................................................... 21
        Experimental Garments .......................................................................... 21
        Motion Capture System ......................................................................... 22
    Data Collection & Analysis .......................................................................... 23

IV. RESULTS .................................................................................................................. 27
    X-factor& X-factor Stretch ............................................................................ 27
    Peak Velocity of the Golf Club ..................................................................... 30

V. DISCUSSIONS AND CONCLUSIONS .................................................................... 32
    X-factor & X-factor Stretch .......................................................................... 32
    Peak Velocity of the Golf Club ..................................................................... 33

VI. LIMITATIONS AND FUTURE RESEARCH ................................................................. 37

APPENDICES ............................................................................................................... 39

REFERENCES .............................................................................................................. 46
<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sampling Population-Age, Physical Attributes and Golfing Experience of Subjects</td>
<td>21</td>
</tr>
<tr>
<td>4. Mean and Standard Deviations of Peak X-factor and X-factor Stretch with/without Wearing a Compression Top when Dividing Two Groups based on the Golfers’ Handicaps</td>
<td>30</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Phases of the Golf Swing: (A) Address Position; (B) Early Backswing; (C) Top of Backswing; (D) Downswing; (E) Prior to Impact; (F) Impact; (G) Mid Follow Through; and (H) End Follow Through (Cheetham et al., 2001)</td>
<td>11</td>
</tr>
<tr>
<td>2. Comparison between the Classic and the Modern Swing (Gluck et al., 2008)</td>
<td>12</td>
</tr>
<tr>
<td>3. Compression Bands Inserted within the Garment (Adidas Techfit)</td>
<td>15</td>
</tr>
<tr>
<td>4. Illustration for X-factor (Gluck et al., 2008)</td>
<td>16</td>
</tr>
<tr>
<td>5. Anatomical Landmarks Guide for Reflective Markers; Front View and Back View (Vena et al., 2011)</td>
<td>24</td>
</tr>
<tr>
<td>6. An Example to Illustrate How to Extract the X-factor, Peak X-factor, X-factor Stretch, and Peak of Velocity of the Golf Club</td>
<td>17</td>
</tr>
<tr>
<td>7. Mean and Standard Deviations of X-factor with/without Wearing a Compression Top</td>
<td>28</td>
</tr>
<tr>
<td>8. Mean and Standard Deviations of X-factor Stretch with/without Wearing a Compression Top</td>
<td>29</td>
</tr>
<tr>
<td>9. Mean and Standard Deviations of Peak Velocity of the Golf Club with/without Wearing a Compression Top</td>
<td>31</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

Elite athletes, in an effort to improve their performance, are increasingly turning to performance enhancing training garments. Currently, the special functional needs of athletes for specific sports are being addressed by the apparel industry (Lee, Katie, & Aaron, 2008). A compression garment is one of the training aids adopted by many athletes and their coaches with a view to improve their performance (Lee et al., 2008), and the compression garment has become an increasingly popular item in the apparel industry, especially sportswear (Fu, Liu, Zhang, Xiong, & Wei, 2012; Pearce, Kidgell, Grikepelis, & Carlson, 2009). Companies providing compression products have made claims that the compression garments enhance proprioception, provide faster recovery, reduce muscle fatigue, increase power, and improve athletic performance (Lee et al., 2008; Pickles, n.d). Although these claims lack evidence, they still have contributed to the popularity of compression garments (Kraemer et al., 1997). There have been conflicting opinions about whether compression garments have positive effects on athletes’ performance during exercise. Therefore, the mechanism for the effects of wearing compression garments must be examined in specific sports.

Recently, golf has become popular all over the world, especially in the U.S., Japan, South Korea, China, India, and the U.K. (Berenberg, 2012). According to Berenberg (2012), the golf industry has had a consistent increase in participants over the last five years. Based on the golf market research conducted by McHardy and Pollard (2005) and Ritchie (2011), it is safe to say that golf is a multi-billion dollar global industry (Berenberg, 2012; Wilson, 2011). Many commercial compression garments have been proposed to provide benefits to athletes, including
golfers. As a result, more golf participants have been wearing compression garments, especially in the U.K, Japan and South Korea. An increased interest in compression garments has led to new golfing fashion; golfers wear a long-sleeve compression top and then layer short-sleeve t-shirts over the compression top. However, little evidence exists for golfers’ performance to support this golf wear trend. 

Most research done on compression garments to date has concentrated on analyzing whether the compression garments enhance athletic performance and increase power during exercise, as well as facilitate a quick recovery after exercise (Doan et al., 2003; Duffield & Portus, 2007; Duffield, Cannon, & King, 2008). To isolate the benefit of compression garments for particular sports, many researchers have studied the effects of compression garments on cricket players’ repeat-sprint and throwing performance (Duffield & Portus, 2007), cyclists’ sprint and aerobic performance (Scanlan, Dascombe, Reaburn, & Osborne, 2008), and volleyball players’ repetitive vertical jump performance (Kraemer et al., 1997). However, no studies have been conducted to examine the effects of the compression tops on golfers’ swing despite the increased demand for compression tops. There has been only one study dealing with golfers’ swing performance: Yang et al. (2011) investigated how spandex garments with multiple compression bands within the garment influenced golfers’ swing performance. Golfers have very specific needs for shoulder extension with no restriction of movement with full swing (Brumitt, Meria, Nee, & Davidson, 2008). Therefore, the purpose of this study was to investigate how wearing a compression top influences golfers’ range of motion when executing a full swing. This study also sought to determine whether wearing a compression top influence the peak of velocity of the golf club by using a motion capture system. The results from this study could potentially
help designers make apparel that improves the performance of golf participants. Also, this study will inform golfers about potential range of motion and trunk performance if they elect to try compression garments to improve their overall game execution.
CHAPTER II
LITERATURE REVIEW

In the context of the present study, this review focuses on literature related to the factors affecting the effectiveness of compression garments in golf. The literature review on the topic is provided in six sections below: Compression Garments, Golf, Golf swing, Golf wear, Biomechanical factors for analysis of golf swing, and Lower back pain in golfers.

Compression Garments

The development of various materials and the advent of high-functional textiles have had significant effects on the functionality of clothing. Fabrics containing elastic are the primary fabrics selected for use in sportswear, due to its outstanding stretch and recovery during motion. The high-elasticity of these fabrics led to development of compression garments (Senthilkumar & Anbumani, 2011). Historically, compression garments have been used for therapeutic purposes in applying compressive force to specific body parts (Higginsa, Naughtona, & Burgessa, 2009; Heid, 2012). In particular, people who have undergone surgical procedures have used compression garments to improve their blood flow and decrease muscle swelling (Heid, 2012). Gandhi et al. (1984) also reported that the compressive force of the garments enabled people having trouble with blood circulation to decrease venous stasis and promote venous blood flow, and it also helped post-operative patients to prevent blood clots, which obstruct blood circulation in vessels (as cited in Lee et al., 2008, para. 2). Given the success of compression garments in helping to improve blood circulation and decrease muscle swelling, these garments have been given to athletes with the intention of providing mechanical support for post exercise recovery (Kraemer et al., 2001). According to Kraemer at al. (2001), the compressive force of the
garments could “promote stable alignment of muscle fibers and attenuate the inflammatory response” (as cited in Jakeman, Byrne, & Eston, 2010, p.1138). Lin et al (2011) also said that the combination of decreased venous stasis and improved blood circulation positively affected athletes’ muscle and circulatory recovery after exercise. In support, Heid (2012) also reported that the compressive distribution has had positive effects on athletes’ performance and the prevention of injuries based on the compression theory.

In the longer term, athletes use intense training and take part in competition to adapt physiologically and improve their performance. In the shorter term, however, the strenuous training could result in muscle damage and soreness and thus decrements in performance (Pickles, n.d; Jakeman, Byrne & Eston, 2010). Friden, Sjostrom, and Ekblom (1981) noted that delayed muscle soreness, which is known as an indicator of exercise induced muscle soreness (Jakeman et al., 2010), might easily lead to future injury (as cited in Gill, Beaven, & Cook, 2006, p. 260). Jakeman et al. (2010) held that minimizing the exercise-induced muscle damage and recovering quickly have become priorities for elite athletes and their coaches, and the combination of minimizing the exercise-induced muscle damage and recovering quickly is the best solution for athletes to have an edge over their rivals (Pickles, n.d.).

Strategies to enhance recovery post exercise have also included muscle massage, immersions in contrasting water temperatures, as well as light exercise. In a study conducted by Gill et al. (2006), the effects of four different methods for muscle recovery on professional rugby players after a rugby game were investigated by measuring creatine kinase, which is an enzyme in blood commonly used to evaluate neuromuscular disease. Gill et al. (2006) said that an increase of creatine kinase in blood accounted for muscle impairment and soreness in response to strenuous exercise. The researchers investigated muscular fatigue and the recovery under
different recovery situations: participants in the first group were doing nothing related to recovery; those in the second group exercised lightly using a stationary bike; those in the third group submerged their bodies in cold and hot water baths alternately; and those in the last group wore compression garments for 12 hours. The results showed both immersion in contrasting water temperatures and wearing compression garments helped remove the creatine kinase more than other methods (Gill et al., 2006). Montgomery, Pyne, Hopkins, Dorman, and Cook (2008) also reported that athletes wearing compression garments or immersing in cold and hot water baths showed faster recovery after strenuous exercise in a basketball tournament. In addition, athletes and their coaches have continued to look for the optimum athletic training wear which can enhance recovery and help their performance. Because athletic training wear has the potential to enhance performance, it is essential to know which training wear is the best for each athlete (Lee et al., 2008).

Even though the advantage of compression garments on recovery of muscle fatigue and improvement in blood circulation has been verified, it is not clear whether the compression garments affect athletic performance to date. Duffield and Portus (2007) studied the effects of three types of full-body compression garments on 10 male cricket players’ performances. Similar to the study conducted by Gill et al (2006), they observed the changes in creatine kinase, and additionally, all participants were asked to rate their perceived muscle soreness. The researchers found that the creatine kinase values of the participants wearing compression garments were significantly lower, and the participants felt less muscle soreness in 24 hours post-exercise. The researchers also measured heart rate, skin temperature, and change in body mass during the exercise protocol. During this exercise protocol, participants were asked to throw five cricket balls as far as they could. In order to measure performance accuracy, the participants were then
asked to hit specific targets. Following the throwing exercise, participants were required to repeatedly sprint and rest for one minute each over a 30 minute time period. Based on the results, the researchers concluded that there was no difference in throwing and repeated sprinting while wearing compression garments, but the compression garments helped minimize perceived muscle soreness post exercise (Duffield & Portus, 2007).

Doan et al. (2003) investigated the effects of compression shorts on track athletes’ jumps and 60-meter sprint performance. For this study, they assessed the athletes’ 60-meter sprint time and height jump performances, as well as measuring their body flexion angles and skin temperatures. Doan et al. (2003) stated that “an initial increase in skin temperature may translate into increased athletic performance and a reduced potential for injury” (p.609). The researchers found that compression garments assisted athletes in maintaining skin temperature and reducing muscle oscillation on ground contact when jumping. The muscle oscillation refers to vibration of muscles caused by repetitive athletic activities, and it is directly related to flexibility of the muscles (Hein, & Vain, 1998). Doan et al. (2003) also stated that the participants who wore compression shorts slightly improved their vertical jump heights. Kraemer et al. (1997) contended that compression garments did not affect the participants’ standing high jumps at the start, but it positively influenced their performance when repetitive jumps occurred. Subsequently, Duffield et al. (2008) conducted further research and indicated that the extent to which compression garments affected the athletes’ performance was negligible.

In another study, Senthilkumar, Anbumani, and Hayavadana (2011) stated that the effects of compression garments on athletic performances depended on the sports or activities for which they were used and the parts of the body under scrutiny. In other words, different sports required movement in certain body parts and not others, which influenced the effects of compression
garments. In addition, a possible mechanism of compression garments revealed by Doan at al. (2003) was that the elasticity of compressive garments provided athletes better flexion and extension torque at the end of an athlete’s swing posture, and it might have reduced injury by assisting the muscles needed for torque (Doan et al., 2003). Since the swinging motion is so frequently used in golf, the study on golfers’ extension during swing is needed to fully investigate the benefit of compression garments for golf.

Golf

Golf is defined as a precision sport using several types of clubs to get balls in a series of holes in as few strokes as possible (Dray, 2011). According to Ritchie (2011), golf came from Scotland in 1457 and spread into Eastern Europe, the United States, and Asia in the late of 19th century. Today, more than 25 million golf players in the U.S are enjoying the game for exercise and social interaction. The number of players has been increasing gradually because anyone can play golf regardless of gender, age, or skill level (Ritchie, 2011). Because golf is a sport with participants varying in abilities taking part in a game together, the golf handicap system seeks to ameliorate these potential differing skills and is an indicator of the level of play that can be anticipated from a given player. The handicap refers to a numerical measure that represents golfers’ potential playing level, and it can be calculated by taking the mean of the scores which the golfer has accomplished by playing 10 times at a specific approved course, minus par of that course (Gregory, n.d.). A lower handicap normally indicates a better golfer (Meister et al., 2011).

It is important in this current research context to determine a handicap limitation in order to recruit participants with similar skill levels (Cheetham, Martin, Mottram, and Laurent, 2011; Yang et al., 2011; &Meister et al., 2011).
Golf Wear

Historically, golf has had strict rules in terms of what to wear and how to dress because the game of golf has been played among the privileged class in restricted membership settings (Callaway, 2011; Park, 2011). The majority of golf courses have had dress codes, so the golfers who play on the courses were required to follow dress guidelines established by membership. In general, the better the quality of the golf course, the stricter the rules governing dress (Csiszar, 2010). Therefore, when the golfers make apparel decisions, clothing selections would be based on the type of golf course chosen. Current trends have many golf players selecting clothing based on fashion and function.

Although golf may not be a very strenuous sport compared to other physically demanding sports, the game of golf takes at least four hours to complete all 18 holes, and golfers are required to move throughout the 18 holes while playing the game. In addition, because golf has generally been an outdoor sport, weather conditions, including sun, wind, rain, or moisture, should be reflected in the functionality of golf wear. Therefore, golf apparel needs to be functional as well as follow the established clothing requirements on the particular golf course (Csiszar, 2010).

In general, golf t-shirts and pants need at least some level of sun protection to block the ultraviolet rays, and the shirts should be made of fabrics with effective moisture management to absorb sweat quickly and keep the body comfortable (Collins, 2010). Moreover, specialized functional products, such as hats, socks, shoes, and gloves, can offer UV protection, increase comfort and improve performance. For instance, functional hats with UV coating prevent golfers’ faces from being directly exposed to sunlight, and socks with better moisture management make
golfers’ feet comfortable during extended periods of walking. Specially designed shoes and gloves provide golfers more traction in order to swing without slipping, as well as assisting them in taking a firm grip of the club during the swing (Csiszar, 2010).

The generally accepted opinion of the ideal golf t-shirt has been that the t-shirt should provide a fit that does not restrict the movement of a full swing (Collins, 2010). However, since some professional golfers have taken part in major competitions wearing a long-sleeve compression top and then layering a short-sleeve t-shirt over the compression top, more golf participants have started to follow the new golf fashion, with the hope that a compression top

Golf Swing

A golf swing is a complex biomechanical movement (Nesbit & Serrano, 2005; Ritchie, 2011). Since good swing posture can generate maximum distance, accuracy, control, and consistency in golf, many golf players think an analysis of their golf swing is important for improving their performance (Maddalozzo, 1987). Elite golfers, therefore, have been trying to achieve perfect swing posture in an effort to improve their performance (Nesbit & Serrano, 2005). To date, some researchers have investigated the kinematics of the ideal full golf swing in order to identify biomechanical factors related to a golf swing (Cheetham et al., 2001; McHardy & Pollard, 2005; Meister et al., 2011; Ritchie, 2011). Prior to these researchers, Maddalozzo (1987) illustrated the sequential body movements made during a full golf swing. This sequence was composed of three major phases: “1) the preparation phase which consists of the grip, posture, stance, and ball position, 2) the execution phase and 3) the recovery or follow-through phase” (Maddalozzo, 1987, p. 6).
The phases have been more commonly classified as address, backswing, downswing, impact, and follow-through, (Figure 1). Address refers to the starting position corresponding to the preparation phase; the backswing means the process where golfers take their club backward to get a maximum hitting effect; downswing is the process where the golfers start to bring their club towards the ball; impact refers to the execution of hitting the ball; and follow-through means the recovery phase of the golf swing (Cheetham et al., 2001; McHardy & Pollard, 2005; Meister et al., 2011; Ritchie, 2011).
Although many golfers vary their swing styles slightly, golf swings have been predominately divided into two swing styles: the *classic* swing and the *modern* swing (Ritchie, 2011). In the *classic* swing, a golfer’s upper body is completely rotated and the pelvis is also rotated along with the upper body during the *backswing*. Ritchie (2011) illustrated the difference between the *classic* swing and the *modern* swing in a sample of right-handed golfers. In the *classic* swing, the golfer’s left heel also lifts off the ground because of the pelvic rotation. Another feature of the *classic* swing is that the golfer has a relatively straight back at the end of the *follow-through* phase (Ritchie, 2011; McHardy & Pollard, 2005) (Figure 2).

![Figure 2. Comparison between the Classic and the Modern Swing (Gluck et al., 2008)](image)

The *modern* golf swing was introduced by a professional golfer, Jack Nicklaus, in the 1960’s. In the *modern* swing, a golfer’s shoulder is largely rotated similar to the *classic* swing.
during backswing. However, golfers’ shoulders have to be turned completely with a fixed pelvis to generate maximum power to strike the ball. The upper body rotation with fixed pelvis results in a larger torque than the classic swing. Also, a golfer’s upper body shows backward bending (similar to a “reverse C”) at the end of the follow-through phase (Ritchie, 2011; Gluck et al., 2008; McHardy & Pollard, 2005). The modern swing allows golfers to strike the balls farther by generating more power than the classic swing (McHardy & Pollard, 2005). The differences between modern and classic swing styles proposed by McHardy and Pollard (2005) have influenced golfers’ range of motion. Therefore, the golf swing style that golfers execute was controlled for this study; since larger torque is required in the modern swing, this study examined golfers with the modern swing.

**Biomechanical Factors for Analysis of Golf Swing**

Meister et al. (2011) investigated the biomechanical factors that affected swing power generation in golfers. The biomechanical factors included $X$-factor, $O$-factor, and $S$-factor. The value of $O$-factor is the extent to which a golfer’s pelvis was cockeyed, and the $S$-factor means “shoulder obliquity” (Meister et al., 2011, p.242). The $X$-factor is defined as “the relative rotation of hip to the shoulder [at the top of backswing], measured in degrees” (Smith, 2011, para. 3). Meister et al. (2011) found that peak $X$-factor and peak $S$-factor were strongly related to golfers’ swing power, and the better golfers showed more consistent values during the swings they executed. In addition, according to Cole and Grimshaw (2009), the higher the value of $X$-factor represented the greater performance in golf swing (as cited in Yang et al., 2011).

Previously, the $X$-factor of golfers has been commonly used in research to analyze swing performance (Cheetham, et al., 2001). Subsequently, research has expanded the analysis to
include *X-factor stretch*. Cheetham et al. (2001) reported that *X-factor stretch* refers to an increase in *X-factor* of golfers early in the *downswing*. The increase in *X-factor* in the *downswing* was caused by golfers’ pelvises immediately reversing direction before upper torso rotated to follow the pelvic transition (Meister et al., 2011). The *X-factor stretch* is measured by determining the maximum *X-factor* angle, which occurs early in the *downswing*, and then subtracting *X-factor* at the top of the *backswing* from the maximum *X-factor*. Cheetham et al. (2001) found that highly skilled golfers have had significantly greater *X-factor stretch*, but there was no significant difference between *X-factor* in less skilled and highly skilled golfer. They, therefore, suggested that measuring *X-factor stretch* is as important as measuring *X-factor* when it comes to analysis of golf swing performance (Cheetham et al. 2001).

In another study, Yang et al. (2011) investigated the effects of wearing a spandex garment with multiple compression bands within the garment on golfers’ swing performance. The researchers measured golfers’ *X-factor, X-factor stretch*, and angular velocity of their own drivers by using six motion capture camcorders (Visol Inc., MotionMaster100, 200 Hz). Yang et al. (2011) concluded the spandex garments with compression bands help to get the higher *X-factor stretch* by increasing maximum *X-factor* in the *downswing*. However, there was no significant difference in *X-factor* and angular velocity of the drivers when evaluating the swing performance. The compression garment evenly provides compressive force to the body parts where it is worn (Higginsa, Naughtona, & Burgessa, 2009; Heid, 2012). However, when the compression bands are inserted within the garment (Figure 3), the bands are aimed to generate a more explosive force to the specific intended muscles (9run, 2011).
Lower Back Pain in Golfers

Since torque in the golf swing needs instantaneous rotative speed to generate the maximum power, many golfers have experienced back muscle soreness post exercise (Meister et al., 2011). According to Gluck, Bendo, and Spivak (2008), lower back pain is one of the most common problems for golfers, and can be caused by overuse of muscles with incorrect swing postures. Vad et al. (2004) also found that the golfers who had a history of lower back pain had a lack of range of motion in “the lumbar spine extension and lead hip internal rotation” (Vad et al., 2004, p.496). Therefore, golfers, in an effort to prevent the lower back muscle soreness post exercise, have been trying to achieve better, more consistent biomechanics without overuse of muscles. With a similar concern, Meister et al. (2011) investigated the sequences of rotational biomechanics during a full swing and compared the biomechanics of professional and amateur golfers. Meister et al. (2011) found that the professional golfers have had more consistent biomechanics in their swings than amateur golfers. They also provided benchmark curves for rotational biomechanics of the professional golfers’ swing in order to provide a point of reference for amateur golfers. The benchmark curves included good biomechanics, which golfers could
follow in order to improve their performance and prevent back muscle overuse during a full swing (Meister et al., 2011). Golfers need an optimal range of motion without causing overuse of muscles and thus the analysis of professionals’ biomechanical factors has the potential of helping a wide range of golfers.

Based on the literature review about the benefits of wearing compression garments, the research so far has shown that compression garments facilitate athletes’ quick recovery after exercise. This study attempted to isolate the benefit of wearing compression garments for golf swing. The main objectives were: (1) to measure $X$-factor of golfers at the top of backswing; (2) to measure $X$-factor stretch of golfers early in the downswing; (3) to measure peak velocity of the golf club throughout golf full swings with/without a compression top using a motion capture system; (4) to compare the values of $X$-factor, $X$-factor stretch, and peak velocity of the golf club to determine if wearing the compression top influences a golfer’s swing performance during golf swing; and (5) to find evidence to support the new golf apparel trend of wearing a long-sleeve compression top and then layering short-sleeve t-shirts over the compression top (Figure 4 and 6).

Figure 4. Illustration for $X$-factor (Gluck et al., 2008)
Therefore, the following two null hypotheses ($H_0 1 & 2$) were developed to compare the effects of wearing a compression top on golfers’ trunk rotation in this study:

$H_0 1$: There is no difference in $X$-factor of golfers at the top of backswing under two conditions: wearing a golf t-shirt with/without a compression top.

$H_0 2$: There is no difference in $X$-factor stretch of golfers early in the downswing under two conditions: wearing a golf t-shirt with/without a compression top.

The following null hypothesis ($H_0 3$) was also developed to compare the effects of wearing a compression top on golfers’ performance measured by velocity of the golf club in this study:

$H_0 3$: There is no difference in the peak velocity of the golf club throughout full golf swings under two conditions: wearing a golf t-shirt with/without a compression top.
In addition, to determine whether any difference found in the *X-factor, X-factor stretch*, and the peak velocity of the golf club when wearing a compression top differed by golfers’ skill levels, the following secondary null hypothesis (H₄₀) was developed.

H₄₀: The *X-factor, X-factor stretch*, and the peak velocity of the golf club when wearing a compression top does not differ by golfers’ skill levels.
CHAPTER III

METHODOLOGY

Design

A repeated measures experimental research design was employed in order to determine if there were differences in range of motion during full golf swing under two conditions: wearing a golf t-shirt with a compression top and wearing a golf t-shirt without the compression top. In the within subjects design, all subjects were subjected to measure and compare their trunk range of motion with and without a compression top in order to see whether wearing the compression top influenced their trunk rotational movement and the velocity of the golf club (Creswell, 2009; Shuttleworth, 2009). For this study, the independent variable was the compression garment, which is defined as “an elastic sportswear designed with compression distribution to enhance the performance of elite athletes” (Lin, Choi, Zhang, Li, Luximon, Yao, & Hu, 2011, p. 1). The dependent variables were defined as range of motion (ROM) of trunk rotation and the peak of velocity of the golf club during full swing. The range of motion refers to “the movement of a joint from full flexion to extension” (Quinn, 2010, para. 1). This research centered on the analysis of the trunk motion during full swing.

Subjects

Prior to conducting the experiment, this study was approved by the Institutional Review Board, Central Michigan University (Appendix A). Subjects were selected by a purposive sampling method. Based on the previous research conducted by Cheetham, Martin, Mottram, and Laurent (2011), Yang et al. (2011), and Meister et al. (2011), a handicap limitation and specific
swing style were required in order to control golfers’ skill levels and their swing postures. Therefore, expert sampling in this current study focused on golf skills and swing style.

The participants consisted of 11 right-handed male golfers who met the following criteria: (1) have been playing golf more than five years; 2) have a handicap of less than 20; and (3) have used the modern golf swing technique based on the previous research conducted by Gluck et al. (2008) and Vena, Budney, Forest, and Carey (2011).

Initially, participants were recruited by posting flyers (Appendix B) and sending e-mails to members of several golf courses around Mount Pleasant, MI and students majoring in the Professional Golf Management (PGM) program at Ferris State University. Flyers and emails indicated the criteria for participating in the study. After recruiting potential participants from responses to flyers, all participants were given a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix C) from the National Academy of Sports Medicine in order to determine physical readiness to participate in this study. If the potential participants answered yes to any of the questions on the PAR-Q, they were eliminated from the study. After the screening measurement, a sample of 11 participants was selected among participants who were physically ready based on PAR-Q results. The age, height, weight, golfing experience, and handicap of all participants are shown in Table 1. All participants were given specific information of how golf swing measurements would be taken and then signed an informed consent (Appendix D) that was approved by Central Michigan University.
<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (years)</th>
<th>Height (feet)</th>
<th>Weight (lb)</th>
<th>Experience (years)</th>
<th>Rounds/Year (rounds/year)</th>
<th>Handicap</th>
<th>Garments Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>5'11&quot;</td>
<td>170.9</td>
<td>25</td>
<td>30</td>
<td>4</td>
<td>MD</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>6'3&quot;</td>
<td>250.0</td>
<td>20</td>
<td>30</td>
<td>15</td>
<td>XL</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>5'6&quot;</td>
<td>170.0</td>
<td>10</td>
<td>30</td>
<td>14</td>
<td>MD</td>
</tr>
<tr>
<td>4</td>
<td>63</td>
<td>6'</td>
<td>183.0</td>
<td>40</td>
<td>80</td>
<td>8</td>
<td>LG</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>5'10&quot;</td>
<td>182.1</td>
<td>15</td>
<td>200</td>
<td>8</td>
<td>MD</td>
</tr>
<tr>
<td>6</td>
<td>58</td>
<td>6'1&quot;</td>
<td>172.0</td>
<td>50</td>
<td>60</td>
<td>10</td>
<td>LG</td>
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<tr>
<td>7</td>
<td>55</td>
<td>5'9&quot;</td>
<td>218.0</td>
<td>45</td>
<td>75</td>
<td>7</td>
<td>XL</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>5'7&quot;</td>
<td>197.0</td>
<td>6</td>
<td>40</td>
<td>20</td>
<td>LG</td>
</tr>
<tr>
<td>9</td>
<td>57</td>
<td>5'10&quot;</td>
<td>205.0</td>
<td>50</td>
<td>100</td>
<td>5</td>
<td>LG</td>
</tr>
<tr>
<td>10</td>
<td>62</td>
<td>5'11&quot;</td>
<td>188.0</td>
<td>48</td>
<td>30</td>
<td>8</td>
<td>LG</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>5'9&quot;</td>
<td>160.0</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>MD</td>
</tr>
<tr>
<td>M</td>
<td>46.27</td>
<td>5'11&quot;</td>
<td>190.57</td>
<td>29.18</td>
<td>62.27</td>
<td>9.90</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>16.00</td>
<td>3&quot;</td>
<td>26.01</td>
<td>17.58</td>
<td>53.17</td>
<td>4.72</td>
<td></td>
</tr>
</tbody>
</table>

Experimental Set-up

**Experimental Garments**

This study aimed to investigate the new golfing fashion on golfers’ trunk rotational motions and peak velocity of the golf club while wearing a long-sleeve compression top and then layering a short-sleeve t-shirt over the compression top. In this study, the same style short-sleeve golf t-shirts and same style long-sleeve compression tops were used. The compression tops were purchased from Under Armour, an athletic wear company that provides high-performance sportswear for athletes. The compression top (style # 1201163, Under Armour) used in this present study was made of 5.0 oz. Polyester/Elastane HeatGear® fabric, innovative fabric technology of Under Armour. The HeatGear® fabric has Moisture Transport System, which absorbs sweat from the body quickly and keeps individuals cooler and drier. The fabric also has 30+ UPF, which protects skin from the harmful ultraviolet rays. In addition, the company insisted the fabric has a 4-Way Stretch function, which can improve the range of body motion by
stretching both vertically and laterally (Under Armour, 2013). Short sleeve golf t-shirts used in the study were purchased from GotApparel. The golf t-shirt was made of 50% Cotton and 50% Polyester, and normal fit. Based on the previous study conducted by Kraemer et al. (1997), all experimental garments were individually assigned by participants’ anthropometric measurement according to the size guidelines of both Under Armour and GotApparel. All remaining clothing, such as underwear, pants, socks, and shoes were not controlled, and were provided by the participant.

*Motion Capture System*

This experiment was performed in a laboratory setting using Qualisys’ motion capture system. The Qualisys’ motion capture system is a Windows-based software, which takes information captured by the camera(s) and provides “2D, 3D, and 6 degree of freedom data” (Senior, 2004, p. 1). Six cameras in the motion capture system were used to observe participants’ swing motion and get quantitative data for analysis. The Qualisys’ motion capture system has been widely used to study individuals’ movements and can exactly quantify their movements. Through capturing the body movements, people can understand injury mechanisms and prevention during exercise, and elite athletes can improve their technique for better results in various sports. The sports where the Qualisys’ motion capture system has been used include track and field, golf, cricket, baseball, tennis, skiing, dance, soccer, martial arts, fencing, rowing and gymnastics (Qualsys AB, 2012).

Six motion capture cameras were placed in the laboratory to capture participants’ body movements during the swing. Before data collection, all cameras were calibrated so that positions of the cameras were obtained and adjusted to capture accurate and confident
measurement. The *Qualisys* motion capture system includes the Automatic Identification of Markers (AIM) function, which is used to capture and track all participants’ movements. Once an AIM model is created, it can be applied throughout the test.

**Data Collection & Analysis**

Data collection took place in the lab setting using the motion capture system. Trunk rotation in transverse plane was recorded during full swing in 11 male golfers with and without wearing a compression top. All participants were asked to swing under two conditions: wearing a long-sleeve compression top underneath a short-sleeve golf t-shirt and wearing only a short-sleeve t-shirt. This study used repeated measures within a subject design, i.e., the same subjects performed under both conditions. The two conditions were randomly determined for each participant.

All participants were asked to change into experimental garments for the motion capture test, and reflective markers (Figure 5) were placed on the participants’ body. According to anatomical landmarks reported by Moore and Dalley (2006), reflective markers were placed according to the list in Table 2 (as cited in Vena, et al., 2011, p. 107). Twelve reflective markers were placed on participants’ upper body in the manner shown in Figure 5 (Vena, et al., 2011), and three markers were attached to the golf club (Meister et al., 2011).
Table 2. Anatomical Landmarks Guide for Reflective Markers (Vena et al., 2011)

<table>
<thead>
<tr>
<th>Segment</th>
<th>Number of Markers</th>
<th>Marker Placement</th>
<th>Marker Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis</td>
<td>2</td>
<td>Left anterior posterior iliac crest</td>
<td>P1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right anterior posterior iliac crest</td>
<td>P2</td>
</tr>
<tr>
<td>Shoulders</td>
<td>2</td>
<td>Left acromion</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right acromion</td>
<td>S2</td>
</tr>
<tr>
<td>Left arm</td>
<td>4</td>
<td>Left elbow,</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left wrist, radius styloid process</td>
<td>A2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left wrist, ulna styloid process</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left hand</td>
<td>A4</td>
</tr>
<tr>
<td>Right arm</td>
<td>4</td>
<td>Right elbow</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right wrist, radius styloid process</td>
<td>A6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right wrist, ulna styloid process</td>
<td>A7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right hand</td>
<td>A8</td>
</tr>
</tbody>
</table>

In order to minimize any errors caused by soft tissue artifact, some markers were wrapped by hypoallergenic 3M Microfoam tape as needed (Vena, et al., 2011). Also, two holes were made in both shoulders of the short sleeve t-shirts, which allowed the markers to be fastened directly to the participants’ bodies when only wearing a golf t-shirt and fastened to the compression top when wearing a golf t-shirt with a compression top. This minimized the errors
caused by the movement of reflective markers due to the shifting of t-shirts across the skin during swing. After markers were placed in pre-selected areas, all participants were given five minutes for warm-up. Warm-up included body stretching and several practice swings before starting the actual experiment. This experiment included repeating a full golf swing ten times with the same type and same weight club, the 7-iron. Lindsay, Horton, and Paley (2002) investigated the effects of different golf clubs on golfers’ trunk range of motion during full swing. Lindsay et al. (2002) found that full swings using the shorter club, 7-iron, required more range of trunk motion compared to the longer club, driver in the research to generate maximum power. During the activity, participants’ swing performances were recorded by using motion capture system.

After capturing ten swings with the initial garment, all participants were asked to change into the second experimental garment(s) and reflective markers were also placed in the same manner as the first experimental condition. After donning the second garment(s), the participants were again given five minutes for warm-up and then a second set of ten swings were captured with the motion cameras. The order of apparel conditions (with/without compression top) varied among the participants.

All markers were captured with six Qualisys’ cameras at sampling rate of 100Hz. The sequences of swing were defined according to the position (x, y, and z) of the club head (Figure 6). The initiation of backswing was defined as start of rising club head. The top of the backswing was defined as maximum vertical position of the golf club throughout the backswing phase. Downswing phase was defined when the direction of the club head changed at the top of backswing. Impact phase was defined when the club head passed the target point which was intended as a ball. From the data captured, X-factor, X-factor stretch, and peak velocity of the
golf club were extracted (Figure 6). $X$-factor was computed as an angular displacement of the trunk in transverse plane at the top of backswing. $X$-factor stretch was computed as a numerical difference between a maximum $X$-factor early in the downswing and $X$-factor at the top of the backswing. The peak of velocity of the club, as shown in the swing cycle, was at the impact phase.

To analyze the data from the experiment, SPSS v20.0 (SPSS Inc., Chicago) statistical software was utilized. The data collected were analyzed by paired sample $t$-test to see whether there were differences in $X$-factor and $X$-factor stretch seen in the golfers’ trunk rotation and peak velocity of the golf club throughout full golf swings based on apparel (Cronk, 2011). The 0.05 level of significance was established as a priori for statistical significance.
CHAPTER IV
RESULTS

*X*-factor refers to a rotational difference between the golfer’s shoulders and pelvis at the top of the backswing (Meister et al., 2011), and *X*-factor stretch refers to the *X*-factor’s increase on the downswing as a consequence of the golfer’s hip rotated first in the downswing. The values of *X*-factor stretch are described as the degree at which the participants’ hips led their shoulders in the downswing (Cheetham, 2011). All values of *X*-factor and *X*-factor stretch presented in Table 3 below are described as right trunk rotations which mean all participants were right-handed golfers, and turned the trunk of their body towards the right, away from the target point intended as a ball.

**X-factor & X-factor Stretch**

A paired-sample t test was conducted to test the hypotheses. First, the mean *X*-factor of golfers wearing a golf t-shirt with a compression top was 33.76 ($SD = 9.50$), and the mean *X*-factor of golfers wearing only a golf t-shirt was 35.46 ($SD = 9.22$) (Table 3 and Figure 7). As the results show in Table 3, no significant difference in *X*-factor under the two conditions was found ($t (10) = -1.422, p = .185$). Therefore, the null hypothesis ($H_0$) was accepted, and the results indicated that the mean *X*-factor of golfers wearing a golf t-shirt with a compression top did not differ from the mean *X*-factor of golfers wearing only a golf t-shirt.
Table 3. Mean and Standard Deviations of X-factor, Peak X-factor, X-factor Stretch, and Peak Velocity of the Golf Club with/without Wearing a Compression Top

<table>
<thead>
<tr>
<th></th>
<th>X-factor</th>
<th>**Peak X-factor</th>
<th>X-factor stretch</th>
<th>Peak velocity of the golf club</th>
</tr>
</thead>
<tbody>
<tr>
<td>With</td>
<td>Mean</td>
<td>33.76</td>
<td>43.22</td>
<td>9.47</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(9.5)</td>
<td>(9.17)</td>
<td>(5.28)</td>
</tr>
<tr>
<td>Without</td>
<td>Mean</td>
<td>35.46</td>
<td>46.45</td>
<td>10.99</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(9.22)</td>
<td>(9.0)</td>
<td>(5.88)</td>
</tr>
<tr>
<td>t</td>
<td>-1.422</td>
<td>-2.423</td>
<td>-3.544</td>
<td>.174</td>
</tr>
<tr>
<td>df</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Sig.</td>
<td>$p = .185$</td>
<td>$p = .036^*$</td>
<td>$p = .005^*$</td>
<td>$p = .866$</td>
</tr>
</tbody>
</table>

With = with wearing a compression top; Without = without wearing a compression top.

* ($p < .05$)

** Numerical values necessary to calculate X-factor stretch ($X$-factor stretch = Peak $X$-factor - $X$-factor)

Figure 7. Mean and Standard Deviations of X-factor with/without Wearing a Compression Top

The mean $X$-factor Stretch of golfers wearing a golf t-shirt with a compression top was 9.47 ($SD = 5.28$), and the mean $X$-factor Stretch of golfers wearing only a golf t-shirt was 10.99 ($SD = 5.88$) (Table 3 and Figure 8). As the results show in Table 3, a significant difference in
*X-factor Stretch* under the two conditions was found \((t(10) = -3.54, p = .005)\). Therefore, the null hypothesis \((H_0)\) was rejected, and the results indicated that when the participants were wearing a golf t-shirt without a compression top, the mean *X-factor Stretch* was higher than when they were wearing a golf t-shirt with a compression top.

![Figure 8. Mean and Standard Deviations of X-factor Stretch with/without Wearing a Compression Top](image)

Since a significant difference in *X-factor Stretch* was found when wearing a compression top, a paired-sample *t* test was conducted to see whether the difference varied by golfers’ skill levels. All participants in this current study were divided into two groups by their handicap: golfers \((N = 6)\) with handicaps between one and nine and golfers \((N = 5)\) with handicaps between ten and twenty because the mean of all participants’ handicap is 9.9. As the results show in Table 4, while no significant difference in *X-factor Stretch* for the golfers with handicaps less than nine under the two conditions was found \((t(5) = -1.52, p = .188)\), significant difference in *X-factor Stretch* for the golfers with handicaps between ten and twenty under the two conditions was
found ($t(4) = -4.86, p = .008$). The mean $X$-factor Stretch for the golfers with handicaps less than nine wearing a golf t-shirt with a compression top was 8.92 ($SD = 6.12$), and the mean $X$-factor Stretch for the golfers with handicaps less than nine wearing only a golf t-shirt was 9.9 ($SD = 6.53$). Also, the mean $X$-factor Stretch for the golfers with handicaps more than ten wearing a golf t-shirt with a compression top was 10.12 ($SD = 4.68$), and the mean $X$-factor Stretch for the golfers with handicaps more than ten wearing only a golf t-shirt was 12.31 ($SD = 5.4$) (Table 4). Therefore, the null hypothesis ($H_0$) was rejected, and the results indicated that the $X$-factor stretch when wearing a compression top differed by golfers’ skill levels.

<table>
<thead>
<tr>
<th>Group 1 (N = 6)</th>
<th>Group 2 (N = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak $X$-factor</td>
</tr>
<tr>
<td>With</td>
<td>46.05</td>
</tr>
<tr>
<td>(SD)</td>
<td>(8.45)</td>
</tr>
<tr>
<td>Without</td>
<td>48.24</td>
</tr>
<tr>
<td>(SD)</td>
<td>(11.4)</td>
</tr>
<tr>
<td>$t$</td>
<td>-1.303</td>
</tr>
<tr>
<td>df</td>
<td>5</td>
</tr>
<tr>
<td>Sig.</td>
<td>$p = .249$</td>
</tr>
</tbody>
</table>

Group 1= The Golfers with Handicaps between One and Nine; Group 2 = The Golfers with Handicaps between Ten and Twenty; With = With Wearing a Compression Top; Without = Without Wearing a Compression Top *(p < .05)*

Peak Velocity of the Golf Club

Third, a paired-sample $t$ test was also conducted to compare the peak velocity of the golf club throughout full golf swings under two conditions: wearing a golf t-shirt with/without a compression top. The peak velocity of the golf club while wearing a golf t-shirt with a compression top was 10583.61 ($SD = 1030.88$), and the peak velocity of the golf club while wearing only a golf t-shirt was 10548.09 ($SD = 934.76$) (Table 3 and Figure 9). As the results
show in Table 3, no significant difference in the peak velocity of the golf club was found ($t(10) = -174, p = .866$). Therefore, the null hypothesis ($H_{03}$) was accepted, and the results indicated that the peak velocity of the golf club while wearing a golf t-shirt with a compression top did not differ from the peak velocity of the golf club while wearing only a golf t-shirt.

Figure 9. Mean and Standard Deviations of Peak Velocity of the Golf Club with/without Wearing a Compression Top
CHAPTER V
DISCUSSIONS AND CONCLUSIONS

The measurement of range of motion has been used to assess athletes’ potential performance in sports, and deficiencies in range of joint motion have been found to result in decreases in athletes’ potential ability to perform their tasks and lead to the injuries they have suffered (Vad et al., 2004). In golf, range of motion has been used to measure the extent of rotational motion (Lindsay et al., 2002; Vad et al., 2004; Meister et al., 2011; Yang et al., 2011). In order to determine whether there was any difference in rotational range of motion during a full golf swing under two conditions, wearing a golf t-shirt with and without a compression top, a repeated measures experimental research was conducted using a Qualisys’ motion capture system. In addition, the study investigated the effect of wearing a compression top on the peak velocity of the golf club.

This study is the first to investigate the effects of current apparel trends in golf (golfers wear a long-sleeve compression top and then layer short-sleeve t-shirts over the compression top) on golfers’ trunk rotational movement and performance measured by velocity of the golf club.

X-factor & X-factor Stretch

Eleven male golfers’ trunk rotations in transverse plane were recorded during full swing under two conditions: wearing a golf t-shirt with and without a compression top. The data was used to calculate rotational differences between a golfer’s shoulders and pelvis at the top of backswing (X-factor) and in the downswing (peak X-factor and X-factor stretch).
According to McLean (2008), the higher \textit{X-factor} and \textit{X-factor stretch} are indicators of the greater performance in golf swing (as cited in Yang et al., 2011, p. 625). The results of the study suggested that rotational differences between the golfers’ shoulders and pelvises at the top of backswing were not statistically different when wearing a compression top. However, the difference in the degree to which the participants’ hips led their shoulders in the downswing was statistically significant when wearing a compression top. This result indicated that when the participants wore a golf t-shirt without the compression top, their pelvises changed direction more quickly in the downswing, resulting in greater increase in the rotational differences between their shoulders and pelvises. With a minimal restriction in rotation when wearing a compression top, an adverse effect on game performance would not be anticipated.

However, in this present study, the \textit{X-factor stretch} for the golfers with handicaps less than nine was not influenced when wearing a compression top. Since the trunk rotational movements of the golfers with a lower handicap were not affected by wearing a compression top, golfers with lower handicaps could potentially wear a compression top with post-game benefits and no adverse effects on their game performance.

\textbf{Peak Velocity of the Golf Club}

According to Meister et al. (2011), peak velocity of the golf club head reported in previous research ranged from 33,000 to 57,000 mm/s. In this study, however, the mean of the peak velocity of the golf club was $10,583.61 \pm 1,030.88$ mm/s for golfers wearing a compression top and $10,548.09 \pm 934.76$ mm/s for golfers wearing only a golf t-shirt. The results were quite lower than the values reported in previous studies. Several different conditions could explain the difference in peak velocity of the golf club. First, previous research used the reflective markers
placed on the golf club head for assessing club speed, but the reflective markers placed on golf club grip were used in this current study because these markers were clearer and caused fewer “dropouts” than the reflective markers placed on the golf club head. Since golf club swing has such a swift movement, the markers on the golf club head might result in more “dropouts” (not captured by cameras) than those on the golf club grip. Therefore, this present study used the reflective markers placed on golf club grip which showed less velocity than the markers on the golf club head in order to obtain peak velocity of the golf club.

Second, according to Lindsay et al. (2002), golf club speed could differ based on the type of golf club used, and they found that the swing with a golf driver had a much higher speed than swing with the 7-iron. Since the 7-iron was chosen with the intention of deriving more rotational motion during the swing, the peak velocity of the 7-iron used in this present study could be different when compared to the peak velocity of the driver or 5-iron used in previous studies (Hume, Keogh, & Reid, 2005; Lindsay et al., 2002; Meister et al., 2011). Third, while Meister et al. (2011) used a plastic ball wrapped by reflective tape, this current study used the target point intended as a ball because of the indoor laboratory setting. It may influence all participants’ swing, preventing them from generating maximum power.

Meister et al. (2011) found that a rotational difference between the golfer’s shoulders and pelvis at the top of the backswing and peak rotational difference between the golfer’s shoulders and pelvis in the downswing were strongly correlated to club speed at impact. The researchers also indicated that the rotational biomechanical factors were essential to generate maximum
power during their golf swing. However, in this current study, even though the increase in rotational differences between the golfers’ shoulders and pelvises in the downswing was statistically different when wearing a compression top, there was no significant difference in peak velocity of the golf club.

In addition, an interesting finding was that the peak velocity of the golf club when wearing a compression top was slightly higher \((M=10583.61, SD=1030.88)\) than the peak velocity of the golf club when not wearing a compression top \((M=10548.09, SD=934.76)\). The difference is not enough to say that golfers’ performance measured by peak velocity of the club improved with wearing a compression top. However, it should be noted that even slight improvement in performance is important for elite golfers in order to have an edge over their competitors. Also, the golfers’ higher peak velocity of the golf club was achieved with less trunk rotation in this present study. Wearing a compression top does not appear to have any negative effects on elite golfers’ performance, and could be considered as a training strategy to decrease post-exercise muscle soreness.

In summary, this study provided empirical support to investigate the effects of wearing a long-sleeve compression top and then layering short-sleeve t-shirts over the compression top for golfers. Based on the results from this study, regardless of the tight fit of compression tops for golfers, there was no significant difference in the peak velocity of the golf club when wearing a compression top \((p = .866)\). In spite of a slight restriction in golfers’ trunk rotational movement, the peak velocity of the golf club was marginally higher during the full swings and thus did not influence performance. Since the golf swing uses specific trunk range of motion and the slight decrease in participants’ trunk rotation did not influence their golf club velocity during the full swings, wearing a compression top did not negatively influence their performance.
Moreover, golfers who have experienced muscle soreness post exercise could use a compression top to facilitate a quick recovery after exercise (Doan et al., 2003; Duffield & Portus, 2007; Duffield, Cannon, & King, 2008). Also, wearing a compression top could be used as a training strategy in order to prevent excessive trunk rotation and reduce golfers’ lower back pain (Grimshaw & Burden, 2000). The results from this study could help elite golfers and their coaches make golf apparel decisions on the basis of potential improvement in performance. In addition, this study lays the foundation for developing compression garments that improve golfers’ swing performance during exercise while continuing to assist in their quick recovery after exercise. The athletic apparel industry could also use the results in marketing compression garments, emphasizing that there are no anticipated negative effects on golfers’ performance when wearing a compression top, and the potential to decrease post-exercise muscle soreness.
CHAPTER VI
LIMITATIONS AND FUTURE RESEARCH

Although efforts were made to decrease limitations for this study, several worth reviewing need to be considered for future research. Since this current research centered on the analysis of the trunk motion during full swing, the rotational difference between golfers’ shoulders and pelvises was only measured to analyze their body movement. Performance was also measured with the peak velocity of the golf club through full golf swing to assess the golfers’ performance. Clearly, more research is needed to understand golfers’ potential range of motion and performances as well as trunk rotation if they elect to try compression garments to improve their overall game execution.

Based on anthropometrical perspective and previous studies, only male golfers were recruited as participants for this experimental study (Lindsay et al., 2002; Vad et al., 2004; Vena, et al., 2011; Yang et al., 2011). Future research should include a more diverse population in order to generally see the effects of wearing a compression top.

This study provided golfers with information about potential range of motion and trunk performance if they wear compression garments in an effort to improve their overall game execution. However, compression tops with a variety of different functions and fit are produced by an array of athletic apparel companies. To provide better understanding about this assortment of compression tops and compare the effects on golfers’ range of motion, future research should examine compression tops based on their fit and differing mechanical properties.

This study found that wearing a compression top somewhat restricted golfers’ trunk rotational movement, but the peak velocity of the golf club was slightly higher during swing. However, this experimental study was conducted in a laboratory motion capture system setting,
which was quite different from outdoor environments, where golf has been typically played. It could be limited to obtain more precise data for participants’ normal swing performances. Therefore, this would suggest that further testing using a bigger sample number in a setting similar to a real golf environment is necessary to generalize this finding.
APPENDIX A

APPROVED LETTER FROM THE INSTITUTIONAL REVIEW BOARD, CENTRAL MICHIGAN UNIVERSITY

DATE: December 19, 2012
TO: So-Young Jung
FROM: Central Michigan University Institutional Review Board 1
PROJECT TITLE: [403703-3] The Effects of Wearing Compression Tops on Golfer's Trunk Motion during Golf Swing
REFERENCE #: 
SUBMISSION TYPE: Amendment/Modification
ACTION: APPROVED
APPROVAL DATE: December 19, 2012
EXPIRATION DATE: December 18, 2013
REVIEW TYPE: Expedited Review

Thank you for your submission of Amendment/Modification materials for this project. The Central Michigan University Institutional Review Board 1 has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSGOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this committee. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this committee.

This project has been determined to be a More than Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of December 18, 2013.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact the CMU IRB office at 989-774-8401 or cmuirb@cmich.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Central Michigan University Institutional Review Board 1’s records.
The testing of compression tops is for research purposes and Central Michigan University.

**VOLUNTEERS NEEDED**
For compression tops’ performance testing

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**Right-handed Male golfers**
1) have been playing golf **more than five years**
2) have a handicap of less than 20
3) have used **“modern” golf swing** technique

* Testing will occur on weekdays in January and February, 2013.
* Participation is expected to take approximately 60 minutes.

**Interested or Question?**
Contact with **Jenna** at **jung2s@cmich.edu**
or 989-854-1371 for further details and scheduling

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**INCENTIVE FOR PARTICIPATION**
After completing the study, participants will receive the **compression top** and **golf t-shirt** used in the experiment (estimated value of $80-100).
APPENDIX C

DATA COLLECTION SHEET AND PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Data Collection Sheet

- Case Number: ______________________________
- Date: ______________________________
- Height: ___________ in / ___________ cm
- Weight: ___________ lbs. / ___________ kg

- Chest measurement: ___________ inch
- Waist measurement: ___________ inch
- T-shirt size: __________________________

- Age: ______________________________
- Golf experience: __________________________ years
- Rounds/year: ______________________________
- Handicap: ______________________________

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Do you feel pain in your chest when you perform physical activity?</td>
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</tr>
<tr>
<td>3. In the past month, have you had chest pain when you were not performing any physical activity?</td>
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<td></td>
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<tr>
<td>4. Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Do you know of any other reason why you should not engage in physical activity?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D

ADULT CONSENT FORM

Adult Consent Form

Study Title: The Effects of Wearing Compression Tops on Golfer’s Trunk Motion during Golf Swing

Research Investigators’ Names and Departments (include Advisor, if researcher is a student):
- So-Young Jung, Graduate Student, Apparel Product Development and Merchandising Technology Department, College of Education and Human Services
- Carol A. Beard, Ph.D., Professor, Apparel Product Development and Merchandising Technology Department, College of Education and Human Services
- Ksenia I. Ustinova, Ph.D., Professor, Physical Therapy Department, College of Health Professions

Contact information for researcher (and Advisor, if researcher is a student):
- So-Young Jung: (989) 854-1371, jung2s@cmich.edu
- Carol A. Beard, Ph.D.: (989) 774-5501, beard2c@cmich.edu

Introductory Statement
You are invited to participate in a research study involving evaluation of athletic compression tops. The details of the study are provided in this consent form. If you have any questions at any time about the study or its details, you may ask the investigators at any time.

What is the purpose of this study?
The purpose of this study is to investigate the effects of wearing a commercial compression top on golfers’ full swing by using motion capture cameras. We will be measuring full golf swing with and without a compression top. We will place thirteen reflective markers on your body that will be used to capture your motion during full swing.

What will I do in this study?
The test will take place using motion capture cameras in HP 1356 at Central Michigan University. You will change into a golf t-shirt and a golf t-shirt with a compression top for the motion capture test and reflective markers will be placed on your body. All markers will be wrapped by hypoallergenic 3M Microfoam surgical tape, which is mainly used in medical institutions and is nonallergenic medical tape. If the hypoallergenic 3M Microfoam surgical tape cause any significant pain or discomfort, you can quit at any time during the experiment. You will be asked to stay in the laboratory for 5 minutes before the test starts to get used to the room temperature, and then you will be given five minutes for warm-up, including body stretching and
several practice swings before starting the actual experiment. Participants will be asked to repeat full golf swing ten times with the same type and same weight club. After taking pictures of the swing with the initial garment, you will be asked to change into the second set of garments and reflective markers will be also placed in the same manner as the first set of garments. You will be asked to swing using the same process as the first test.

**How long will it take me to do this?**
Participation is expected to take approximately 60 minutes.

**Are there any risks of participating in the study?**
There is no risk for skilled golfers that routinely swing a golf club more than 20 times in a single game.

**What are the benefits of participating in the study?**
By participating in this study, you will be helping us to examine the effects of compression top on golfers’ performance while swinging. For the professional golfers, an analysis of their golf swing is important for improving their performance. If you want to analyze your performance, it would be an excellent opportunity for you to get performance information from these tests.

**Will anyone know what I do or say in this study (Confidentiality)?**
The information collected in this study will remain confidential. Participants will be assigned a number and all information collected will be identified by subject number. The information will be kept on a password protected computer in the laboratory and only the researchers will have an access to the information.

**Will I receive any compensation for participation?**
After completing the study, you can get the compression top and t-shirt used in the experiment as compensation for participation. In addition, if participants want, they can get the results from motion capture cameras.

**Is there a different way for me to receive this compensation or the benefits of this study?**
The results of this study will be available in a report form at its conclusion. Compensation is only for subjects who participate in the study.

**Who can I contact for information about this study?**
For any questions, you may have regarding this study, please contact with
- So-Young Jung: (989) 854-1371, jung2s@cmich.edu
- Carol A. Beard, Ph.D.: (989) 774-5501, beard2c@cmich.edu

You are free to refuse to participate in this research project or to withdraw your consent and discontinue participation in the project at any time without penalty, but no garment will be given to you.

Your participation will not affect your relationship with the institution(s) involved in this research project.
If you are not satisfied with the manner in which this study is being conducted, you may report (anonymously if you so choose) any complaints to the Institutional Review Board by calling 989-774-6777, or addressing a letter to the Institutional Review Board, 251 Foust Hall Central Michigan University, Mt. Pleasant, MI 48859.

My signature below indicates that all my questions have been answered. I agree to participate in the project as described above.

____________________________  __________________
Signature of Subject Date Signed

A copy of this form has been given to me. _________ Subject’s Initials

____________________________  __________________
Signature of Responsible Investigator Date Signed
REFERENCES


A literature review of swing biomechanics and injury prevention. The Spine Journal, 8,
778–788.

Gregory, J. (n.d.). What is a golf handicap? Retrieved from eHow.com website:


Retrieved from Appalachian Mountain Club website:
http://www.outdoors.org/publications/outdoors/2012/equipped/compression-clothing-
and-athletic-performance.cfm


on physiological and performance measures in an simulated game-specific circuit for
netball. Journal of Science and Medicine in Sport, 12, 223-226.


Jakeman, J. R., Byrne, C., & Eston, R.G. (2010). Lower limb compression garment improves
recovery from exercise-induced muscle damage in young, active females. European
Journal of Applied Physiology, 109, 1137-1144. DOI 10.1007/s00421-010-1464-0


Quinn, E. (2010, June 3). What is range of motion (ROM)? Retrieved from About.com website: http://sportsmedicine.about.com/od/glossary/g/ROM_def.htm


