ORIGINAL RESEARCH

A COMPARISON OF THE IMMEDIATE EFFECTS OF ECCENTRIC TRAINING VS. STATIC STRETCH ON HAMSTRING FLEXIBILITY IN HIGH SCHOOL AND COLLEGE ATHLETES

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ABSTRACT

Background. A pre-event static stretching program is often used to prepare an athlete for competition. Recent studies have suggested that static stretching may not be an effective method for stretching the muscle prior to competition.

Objective. The intent of this study was to compare the immediate effect of static stretching, eccentric training, and no stretching/training on hamstring flexibility in high school and college athletes.

Methods. Seventy-five athletes, with a mean age of 17.22 (+ /- 1.30) were randomly assigned to one of three groups – thirty- second static stretch one time, an eccentric training protocol through a full range of motion, and a control group. All athletes had limited hamstring flexibility, defined as a 20° loss of knee extension measured with the femur held at 90° of hip flexion.

Results. A significant difference was indicated by follow up analysis between the control group (gain = -1.08°) and both the static stretch (gain = 5.05°) and the eccentric training group (gain = 9.48°). In addition, the gains in the eccentric training group were significantly greater than the static stretch group.

Discussion and Conclusion. The findings of this study reveal that one session of eccentrically training through a full range of motion improved hamstring flexibility better than the gains made by a static stretch group or a control group.

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INTRODUCTION

Most experts consider aerobic conditioning, strength training, and flexibility to be the three key components of a conditioning program.[1-3] By definition, flexibility is the ability of a muscle to lengthen and allow one joint (or more than one joint in a series) to move through a range of motion, and the loss of flexibility is a decrease in the ability of a muscle to perform.[4] Reduced injury risk,[1-3] pain relief,[5] and improved athletic performance[6,7] are reasons provided for incorporating flexibility training into a training program.

Static stretching, defined as elongation of a muscle to tolerance and sustaining the position for a length of time,[6, 8] is considered the gold standard in flexibility training. Some authors have questioned the importance of using static stretching to help reduce injuries and to improve athletic performance.[1-3] Recent studies have found that static stretching is not an effective way to reduce injury rates,[9-11] and may actually inhibit athletic performance.[12] Murphy[13] made a compelling argument against the use of static stretching. Although static stretching is often used as a part of preactivity preparation, Murphy[13] argued that the nature of static stretching is passive and does nothing to warm a muscle; further, although the hamstring muscle is the most frequently stretched muscle, it is also the most commonly strained.

A better option for increasing flexibility, according to Murphy,[13] would be an activity that is more dynamic by nature. Murphy,[13] therefore, introduced what is referred to as "dynamic range of motion." To dynamically stretch a muscle, the antagonist group is contracted thus allowing the agonist to elongate naturally in a relaxed state. The dynamic nature of the activity, in theory, would cause a warming effect in the muscle, and the muscle would be more pliable and accommodating to the stretch, leading to an increase in the flexibility of the muscle.

In contrast to the belief of Murphy,[13] Bandy et al[15] compared the flexibility gains made by subjects participating in a dynamic range of motion program with gains subjects achieved using a static stretching program. The gains achieved by the group in the static stretching program were greater than those achieved with dynamic range of motion.

More recently, Nelson and Bandy[16] investigated a flexibility program which consisted of eccentrically training a muscle through a full range of motion. Previous literature suggests that most injuries occur in the eccentric phase of activity.[9] For example, the hamstring muscles are most commonly injured when working eccentrically while decelerating or landing. Eccentrically training a muscle through a full range of motion, theoretically, could reduce injury rates, improve athletic performance, and improve flexibility. Nelson and Bandy[16] compared the flexibility gains made over a six week period of time by a control group, a static stretch group, and a group who eccentrically trained the muscle through a full range of motion. The findings of the study were a significant increase in flexibility in the static stretch group (12.05°) and in the group who trained eccentrically through a full range of motion (12.79°) over the control group (a 1.17° change). The difference in the flexibility gained between the static stretch group and the eccentric training group was not significantly different. This study offers compelling evidence to incorporate eccentric training into any training program.

While it has been found that eccentrically training a muscle through a full range of motion will improve flexibility over a period of six weeks as well as static stretching, no study has been conducted to determine the immediate effects of one bout of eccentric training compared to one bout of static stretching and comparing both with a control. A pre-event stretching program is often used by coaches to prepare an individual for athletic competitions. Some of the goals of pre-event flexibility training program include decreasing the chances the individual will sustain an injury, warming the muscle, and improving the flexibility of the muscle in preparation for the activity. Theoretically, eccentric training will decrease injury rates and warm a muscle, but no study has been performed to determine the effects a single bout of eccentric training has on flexibility. Therefore, the purpose of the study is to determine if one bout of eccentric training through a full range of motion will improve flexibility and to compare the results with one bout of static stretching and a control group.

METHODS

Subjects

Eighty-seven subjects were recruited on a voluntary basis to participate in the study. The authors felt attrition would be low given the design of the study. By recruiting eighty-seven subjects this ensured the study would have the appropriate number needed when complete. Subjects were high school football players at Texarkana, Arkansas High School and Liberty Eylau High School, and college baseball players at Texarkana Community College. Subjects over the age of 18 signed an informed consent form. Subjects under 18 years of age had a parent or guardian sign the informed consent form and the minor signed an informed assent form. This study was approved by the Institutional Review Board of the University of Central Arkansas.

Volunteers for the study had to meet three requirements. The first requirement was the test extremity must have had no impairment to the hip, knee, thigh, or the low back for the previous year. The second requirement was the test extremity had to exhibit hamstring tightness. A deficit of 20° from full knee extension with the hip at 90° was defined as tight hamstrings. The subjects were also all high school and college athletes between the ages of 15 and 21 years.

Equipment

A double-armed transparent plastic goniometer was used for measuring hamstring flexibility. The protractor portion of the goniometer was divided into one-degree increments. The goniometer arms were 12 inches in length. A bubble was removed from a carpenter's level and fixated to the goniometer to help ensure maintenance of the hip at a 90° angle.

Procedures

Measurement of hamstring flexibility was performed using the 90/90 test for hamstring flexibility described by Reese and Bandy.[17] The subjects were positioned in supine with the hip and knee flexed to 90°. The researchers palpated the lateral epicondyle of the femur and centered the goniometer over that landmark. The greater trochanter of the femur and the lateral malleolus of the tibia were marked. The goniometer was aligned with the lateral malleolus and the greater trochanter and centered over the lateral epicondyle. *(Figure 1)*

The markings on the goniometer were concealed with a piece of paper. While one researcher held the goniometer the other researcher moved the leg passively toward terminal extension. The point at which the researcher felt a firm resistance was defined as terminal extension. When the subject reached terminal extension the researcher holding the goniometer made sure proper alignment was maintained. An assisting examiner read and recorded the measurements on the blinded goniometer. Full hamstring flexibility was zero degrees on the goniometer. The subjects had no warm-up before data collection.

Figure 1. The 90/90 test for measuring hamstring flexibility.

Since reliability had been established previously in the study by Nelson and Bandy,[16] and the same researchers were performing the measurement, the reliability study was not replicated. A pretest measurement was taken on 87 males using the procedures using the 90/90 test for hamstring flexibility described. While 87 subjects were measured, 75 males met the criteria that had been established for the study. The subjects were randomly assigned to one of three groups.

The control group consisted of 24 subjects and was measured and then later re-measured. The length of time between the two measurements of the control group was similar to those in the study group. The subjects in the control group performed no stretching before being remeasured.

The eccentric training group (n = 25) was measured then performed full range of motion eccentric training for the hamstring muscles. The subject lay supine with the left lower extremity fully extended. A 3 foot (0.91 m) piece of black theraband was held by the ends in each hand with the mid-section of the band wrapped around the right heel. The exercise started with the right knee locked in full extension and the hip in 0 degrees of extension. *(Figure 2)* The subject then pulled the hip into full flexion by pulling on the ends of the band with the arms. *(Figure 3)* The subject was to stop when he felt a gentle stretch. The position where the subject felt the gentle stretch was defined as full hip flexion. As the subject pulled the leg into hip flexion he was to resist the flexion motion by eccentrically contracting the hamstring muscles. The subject gave enough resistance to slow the hip flexion moment to take five seconds to complete. The eccentric activity was performed six times for a total stretch time of 30 seconds.

The static stretch group (n = 26) performed a single 30 second static stretch using methods described by Bandy et al.[1,15] The subject performed the hamstring stretch by standing erect with the left foot on the ground, toes pointed forward. *(Figure 4)* The heel of the right foot was on the seat of a chair or on a box. The subject's toes on the right lower extremity were pointed toward the ceiling. The subject then flexed forward at the hips, while maintaining a neutral spine. The subject was instructed to keep the right knee fully extended. The subject flexed forward at the hips until a gentle stretch was felt in the posterior thigh. The position of stretch was held for 30 seconds.

Data Analysis

Means (and standard deviation) for all groups and all measurements were calculated. A 3 (group) x 2 (test) analysis of variance (ANOVA) with repeated measures on one variable (test) was used to analyze the data. Since an interaction was found, appropriate post hoc tests were performed to interpret the findings and are described in the results section. An alpha level of $p < .05$ was considered appropriate for the level of significance.

RESULTS

Seventy-five male subjects, with mean age of 17.22 years (SD = 1.30), completed all requirements for this study. Twenty-four subjects, with a mean age of 17.18 years (SD = 1.84) served the control group. The static group consisted of 26 subjects with a mean age of 17.22 years (SD = .76) and statically stretched the hamstrings muscles. Twenty-five subjects comprised the eccentric group and had a mean age of 17.27 years (SD = 0.96). The mean values for the pretest and post-test measurements of the control group for the degrees of knee extension were 31.42 degrees (SD = 9.97) and 32.50 degrees (SD = 10.19), respectively. The ICC (3,2) value calculated for pretest-post-test knee extension data of the control group was .95.

The Table presents the means for pretest and posttest measurements and gain scores for each group. Results of the two-way ANOVA (group x test) indicated a significant difference for test (df = 1,72; F = 59.16; p < .05), group (df =2,72; F = 1.034; p < .05) and interaction (df = 2,72; F = 25.59; p < .05).

Figure 2. *Above,* eccentric training, initial position. *Below,* final position of full hip flexion.

In order to interpret the group x test significant interaction, three follow-up statistical analyses were performed. First, three dependent t tests were calculated on the pretest to posttest change for each group. Using a Bonferroni correction to avoid inflation of the alpha level due to the use of multiple t tests, the alpha level was adjusted to p < .015. The dependant t tests indicated significant increases in hamstring flexibility in the group statically stretching (df = 25; t = 5.66; p < .015) and the eccentric group (df = 24; t = 6.85; p < .015), but no significant change in hamstring flexibility in the control group (df = 23; t = 1.83; p > .015).

Second, a one-way ANOVA was calculated to assess whether any significant differences existed in the pretest scores across the three groups. Results of these analyses indicated no significant difference (df = 2,72; F = .47; p > .05). A one-way ANOVA was calculated to assess if any difference existed across the posttest scores of the three groups. Results indicated a significant difference (df = 2,72; F = 5.15; p < .05). Tukey HSD post hoc analyses indicated that the mean posttest score of the static group (mean =25.77, SD = 9.15) was significantly different from the posttest score for the control group (mean = 32.50, SD = 10.19). Also, the posttest score for the eccentric group (mean = 24.12, SD = 9.66) was significantly different from the posttest score for the control group. The static and eccentric groups did not differ from each other.

Finally, in an attempt to summarize the data, an additional analysis using a one-way ANOVA on gain scores was calculated, revealing a significant difference between groups (df =2; F = 25.585; p < .05). Post hoc analysis using a Tukey HSD test indicated a significant difference between the gain in the static stretch group (mean = 5.50, SD = 4.50) and the control group (mean = -1.08, SD = 2.90), and the eccentric group (mean = 9.48, SD = 6.92) and the control group. Finally, the eccentric group showed a significantly greater gain than the static stretch group.

DISCUSSION

The groups performing one bout of static stretching and one bout of eccentric training showed significantly greater gains in flexibility than the control group. The group performing one bout of eccentric training showed a significantly greater gain in flexibility than the static stretch group. To date, this is the only study to compare the immediate effects of one bout of eccentric training on changes in muscle flexibility. The results support the theory that the immediate effect of performing eccentric training through a full range of motion is an increase in muscle flexibility.

Eccentric training has been shown to improve flexibility not only from one bout of training as in this study, but also over a six week training program.[16] The gains achieved by a six week program of static stretching and a six week program of eccentric training were very similar. Static stretching gained 12.04° and eccentric training gained 12.79° over the six week training program. Comparing the gains made over six weeks with the gains made with one bout of stretching or training, the gains were less with the single bout of training or stretching. While the gains were less with only one bout of activity, the gains were still significant when compared with a control.

Figure 3. Static stretching position.

No studies to date have examined the use of eccentric training to reduce injury rates, but the SAID (Specific Adaptation to Imposed Demand) principle states that a muscle will adapt to the imposed demands.[18] If the muscle adapts to the imposed demand of eccentrically training, theoretically, injury rates would be lower since most injuries occur during the eccentric phase of activity. Strength gains from eccentrically training a muscle would, theoretically, also improve performance. The need to use a resistance band does make eccentric training more difficult than static stretching, but the author of this study believes the benefits achieved outweigh the added complexity of using resistance bands.

Important clinical implications exist for eccentric training through a full range of motion. In many cases, the goal for clinicians and patients is a restoration of normal functional motion. Normal motion requires the patient to have the flexibility and the strength to perform the movement. Strengthening through a full range of motion will increase the likelihood that the patient will not only maintain the range achieved but will help ensure that the patient is able to use the range functionally. Eccentrically training through a full range of motion, theoretically, will improve the functional ability of the extremity by improving not only the flexibility but also the strength in that range.

A patient with weakness around a particular joint may not move the joint through a full range and structures around the area will often shorten leaving the patient with limited mobility. While static stretching has been proven to improve flexibility, the ability of static stretching to strengthen through and entire range of motion is

Table. Mean and standard deviation scores (in degrees) for pretest, posttest, and gain scores (in degrees) of knee flexion for each level of group.

	Group					
	Control (n = 24)		**Static (n = 26)**		**Eccentric (n = 25)**	
	x̄	**SD**	**x̄**	**SD**	**x̄**	**SD**
Pretest	31.42	9.97	31.27	8.70	33.60	9.89
Posttest	32.50	10.19	25.77	9.15	24.12	9.66
Gain (difference)	-1.08	2.90	5.50	4.50	9.48	6.92

doubtful. Eccentric training is strengthening the muscle by having it contract as it lengthens. A patient eccentrically training through a full range of motion will be gaining range of motion and strength at the same time, thus, making the activity more functional. This type of training could also save time by combining the strengthening and flexibility components into one activity.

More research is needed to determine if tangible gains can be made in strength, injury reduction, and performance enhancement through the use of eccentric training. In addition, future studies should address the effects of eccentric training on individuals across a diverse age group and include females.

CONCLUSION

In high school and college aged male athletes, hamstring flexibility gains made from one bout of eccentric training (as measured by hip flexion range of motion gains) were significantly better than the gains made by a static stretch group and a control group. This study provides evidence that when dealing with the immediate effects of stretching, flexibility programs may actually be enhanced by replacing static stretching with eccentric training.

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INVITED CLINICAL COMMENTARY

PRE-PARTICIPATION SCREENING: THE USE OF FUNDAMENTAL MOVEMENTS AS AN ASSESSMENT OF FUNCTION – PART 1

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ABSTRACT

To prepare an athlete for the wide variety of activities needed to participate in their sport, the analysis of fundamental movements should be incorporated into pre-participation screening in order to determine who possesses, or lacks, the ability to perform certain essential movements. In a series of two articles, the background and rationale for the analysis of fundamental movement will be provided. In addition, one such evaluation tool that attempts to assess the fundamental movement patterns performed by an individual, the Functional Movement Screen (FMS™), will be described. Three of the seven fundamental movement patterns that comprise the FMS™ are described in detail in Part I: deep squat, hurdle step, and in-line lunge. Part II of this series, which will be published in the August issue of *NAJSPT*, will provide a brief review of the analysis of fundamental movements, as well a detailed description of the four additional patterns that complement those presented in Part I (to complete the total of seven fundamental movement patterns which comprise the FMS™): shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability.

The intent of this two part series is to introduce the concept of the evaluation of fundamental movements, whether it is the FMS™ system or a different system devised by another clinician. Such a functional assessment should be incorporated into pre-participation screening in order to determine whether the athlete has the essential movements needed to participate in sports activities with a decreased risk of injury.

Key Words. pre-participation screening, performance tests, function

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INTRODUCTION

Over the last 20 years, the profession of sports rehabilitation has undergone a trend away from traditional, isolated assessment and strengthening toward an integrated, functional approach, incorporating the principles of proprioceptive neuromuscular fascilitation (PNF), muscle synergy, and motor learning.[1] However, it is difficult to develop and refer to protocols as "functional" when a functional evaluation standard does not exist. In many situations, rehabilitation professionals in sports settings are far too anxious to perform specific isolated, objective testing for joints and muscles. Likewise, these clinicians often perform sports performance and specific skill assessments without first examining functional movement. It is important to inspect and understand common fundamental aspects of human movement realizing that similar movements occur throughout many athletic activities and applications. The rehabilitation professional must realize that in order to prepare individuals for a wide variety of activities, fundamental movements should be assessed.

In the traditional sports medicine model, pre-participation physicals are followed by performance assessments. This systematic process doesn't seem to provide enough baseline information when assessing an individual's preparedness for activity. Commonly, the medical pre-participation or rehabilitation examination includes only information that will exclude an individual from participating in certain activities. The perception of many past researchers is that no set standards exist for determining who is physically prepared to participate in activities.[2-5] Recently, numerous medical societies have collaborated and attempted to establish more uniformity in this area, however, only suggestions for baseline medical parameters required for participation were provided.[6] Ideally, collaboration should also occur among professionals to determine what the baseline for fundamental movement should be and if individuals should be allowed to participate if they are unable to perform movements at a basic level.

In the typical pre-participation screening exam, once the pre-participation medical examination is performed the active individual is then asked to complete performance tests. Commonly recommended performance tests include sit-ups, push-ups, endurance runs, sprints, and agility activities.[7] In many athletic and occupational settings these performance activities become more specific to the tasks needed for defined areas of performance.

Performance tests function to gather baseline quantitative information and then attempt to make recommendations and establish goals. The recommendations are based on standardized normative information, which may not be relative to the individual's specific needs. Likewise, in many cases, performance tests provide objective information that fails to evaluate the efficiency by which individuals perform certain movements. Little consideration is given to functional movement deficits, which may limit performance and predispose the individual to micro-traumatic injury.

Prescribed strength and conditioning programs often work to improve agility, speed, and strength without consideration for perfection or efficiency of underlying functional movement. An example would be a person who has an above average score on the number of sit-ups performed during a test but is performing very inefficiently by compensating and initiating the movement with the upper body and cervical spine as compared to the trunk. Compare this person to an individual who scores above average on the number of sit-ups, but is performing very efficiently and doesn't utilize compensatory movements to achieve the sit-up. These two individuals would each be deemed "above average" without noting their individual movement inefficiencies. The question arises: If major deficiencies are noted in their functional movement patterns, then should their performance be judged as equal? These two individuals would likely have significant differences in functional mobility and stability; however, without assessing their functional mobility and stability it is inappropriate to assume differences.

The main goal in performing pre-participation or performance screenings is to decrease injuries, enhance performance, and ultimately improve quality of life.[4,6,8] Currently, the research is inconsistent on whether the pre-participation or performance screenings and standardized fitness measures have the ability to achieve this main goal.[4,5] A reason for the lack of predictive value of screenings is that the standardized screenings do not provide individualized, fundamental analysis of an individual's movements. The authors of this clinical commentary suggest that analysis of fundamental movements should be incorporated into pre-season screening in order to determine who possesses, or lacks, the ability to perform certain essential movements.

THE FUNCTIONAL MOVEMENT SCREEN™

The Functional Movement Screen (FMS)™ is one evaluation tool that attempts to assess the fundamental movement patterns of an individual.[9-11] This assessment tool fills the void between the pre-participation/pre-placement screenings and performance tests by evaluating individuals in a dynamic and functional capacity. A screening tool such as this offers a different approach to injury prevention and performance predictability. When used as a part of a comprehensive assessment, the FMS™ will lead to individualized, specific, functional recommendations for physical fitness protocols in athletic and active population groups.

The FMS™ is comprised of seven fundamental movement patterns that require a balance of mobility and stability. These fundamental movement patterns are designed to provide observable performance of basic locomotor, manipulative, and stabilizing movements. The tests place the individual in extreme positions where weaknesses and imbalances become noticeable if appropriate stability and mobility is not utilized. It has been observed that many individuals who perform at very high levels during activities are unable to perform these simple movements.[11,12] These individuals should be considered to be utilizing compensatory movement patterns during their activities, sacrificing efficient movements for inefficient ones in order to perform at high levels. If compensations continue, then poor movement patterns are reinforced leading to poor biomechanics and ultimately the potential of micro- or macro-traumatic injury.

The FMS™ tests were created based on fundamental proprioceptive and kinesthetic awareness principles. Each test is a specific movement, which requires appropriate function of the body's kinetic linking system. The kinetic link model, used to analyze movement, depicts the body as a linked system of interdependent segments. These segments often work in a proximal-to-distal sequence, in order to impart a desired action at the distal segment.[13] An important aspect of this system is the body's proprioceptive abilities. Proprioception can be defined as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement and joint position sense.[14] Proprioceptors in each segment of the kinetic chain must function properly in order for efficient movement patterns to occur.

During growth and development, an individual's proprioceptors are developed through reflexive movements in order to perform basic motor tasks. This development occurs from proximal to distal, the infant learning to first stabilize the proximal joints in the spine and torso and eventually the distal joints of the extremities. This progression occurs due to maturation and learning. The infant learns fundamental movements by responding to a variety of stimuli, through the process of developmental motor learning. As growth and development progresses, the proximal to distal process becomes operational and has a tendency to reverse itself. The process of movement regression slowly evolves in a distal to proximal direction.[15] This regression occurs as individuals gravitate toward specific skills and movements through habit, lifestyles, and training.

Application Examples

Firefighters initially train through controlled, voluntary movements. Then, through repetition, the movement becomes stored centrally as a motor program. The motor program eventually requires fewer cognitive commands leading to improved subconscious performance of the task. This subconscious performance involves the highest levels of central nervous system function, know as cognitive programming.[14] In this example, problems would arise when the movements and training being "learned" are performed incorrectly, inefficiently, or asymmetrically.

A sport-specific example is a football lineman entering preseason practice who does not have the requisite balance of mobility or stability to perform a specific skill such as blocking. The athlete may perform the skill utilizing compensatory movement patterns in order to overcome the stability or mobility inefficiencies. The compensatory movement pattern will then be reinforced throughout the training process. In such an example, the individual creates a poor movement pattern that will be subconsciously utilized whenever the task is performed. Programmed altered movement patterns have the potential to lead to further mobility and stability imbalances, which have previously been identified as risk factors for injury.[16-18]

An alternative explanation for development of poor movement patterns is the presence of previous injuries. Individuals who have suffered an injury may have a decrease in proprioceptive input, if untreated or treated inappropriately.[14,19] A disruption in proprioceptive performance will have a negative effect on the kinetic linking system. The result will be altered mobility, stability, and asymmetric influences, eventually leading to compensatory movement patterns. This may be a reason why prior injuries have been determined to be one of the more significant risk factors in predisposing individuals to repeat injuries.[19,20]

Determining which risk factor has a larger influence on injury, previous injuries or strength/flexibility imbalances, is difficult. In either case, both lead to deficiencies in functional performance. It has been determined that these functional deficits lead to pain, injury, and decreased performance. Cholewicki et al [21] demonstrated that limitations in stability in the spine led to muscular compensations, fatigue, and pain. Gardner-Morse et al [22] determined that spinal instabilities result in degenerative changes due to the muscle activation strategies, which may be disrupted due to previous injury, stiffness, or fatigue. In addition, Battie et al[23] demonstrated that individuals with previous low-back pain performed timed shuttle runs at a significantly lower pace than individuals who did not have previous low-back pain.

Therefore, an important factor in preventing injuries and improving performance is to quickly identify deficits in mobility and stability because of their influences on creating altered motor programs throughout the kinetic chain. The complexity of the kinetic linking system makes the evaluation of weaknesses using conventional, static methods difficult. For that reason, utilizing functional tests that incorporate the entire kinetic chain need to be utilized to isolate deficiencies in the system.[8,19,23] The FMS™ is designed to identify individuals who have developed compensatory movement patterns in the kinetic chain. This identification is accomplished by observing right and left side imbalances and mobility and stability weaknesses. The seven movements in the FMS™ attempt to challenge the body's ability to facilitate movement through the proximal-to-distal sequence. This course of movement in the kinetic chain allows the body to produce movement patterns more efficiently. The correct movement patterns were initially formed during growth and development. However, due to a weakness or dysfunction in the kinetic linking system, a poor movement pattern may have resulted. Once an inefficient movement pattern has been isolated by the FMS™, functional prevention strategies can be instituted to avoid problems such as imbalance, micro-traumatic breakdown, and injury.

Scoring the Functional Movement Screen™

The scoring for the FMS™ consists of four possibilities. The scores range from zero to three, three being the best possible score. The four basic scores are quite simple in philosophy. An individual is given a score of zero if at any time during the testing he/she has pain anywhere in the body. If pain occurs, a score of zero is given and the painful area is noted. A score of one is given if the person is unable to complete the movement pattern or is unable to assume the position to perform the movement. A score of two is given if the person is able to complete the movement but must compensate in some way to perform the fundamental movement. A score of three is given if the person performs the movement correctly without any compensation. Specific comments should be noted defining why a score of three was not obtained

The majority of the tests in the FMS™ test right and left sides respectively, and it is important that both sides are scored. The lower score of the two sides is recorded and is counted toward the total; however it is important to note imbalances that are present between right and left sides.

Three tests have additional clearing screens which are graded as positive or negative. These clearing movements only consider pain, if a person has pain then that portion of the test is scored positive and if there is no pain then it is scored negative. The clearing tests affect the total score for the particular tests in which they are used. If a person has a positive clearing screen test then the score will be zero.

All scores for the right and left sides, and those for the tests which are associated with the clearing screens, should be recorded. By documenting all the scores, even if they are zeros, the sports rehabilitation professional will have a better understanding of the impairments identified when performing an evaluation. It is important to note that only the lowest score is recorded and considered when tallying the total score. The best total score that can be attained on the FMS™ is twenty-one.

DESCRIPTION OF THE FMS™ TESTS

The following are descriptions of three of the seven specific tests used in the FMS™ and their scoring system. Each test is followed by tips for testing developed by the authors as well as clinical implications related to the findings of the test.

Deep Squat

Purpose. The squat is a movement needed in most athletic events. It is the ready position and is required for most power movements involving the lower extremities. The deep squat is a test that challenges total body mechanics when performed properly. The deep squat is used to assess bilateral, symmetrical, functional mobility of the hips, knees, and ankles. The dowel held overhead assesses bilateral, symmetrical mobility of the shoulders as well as the thoracic spine.

Description. The individual assumes the starting position by placing his/her feet approximately shoulder width apart and the feet aligned in the sagittal plane. The individual then adjusts their hands on the dowel to assume a 90-degree angle of the elbows with the dowel overhead. Next, the dowel is pressed overhead with the shoulders flexed and abducted, and the elbows extended. The individual is then instructed to descend slowly into a squat position. The squat position should be assumed with the heels on the floor, head and chest facing forward, and the dowel maximally pressed overhead. As many as three repetitions may be performed. If the criteria for a score of III is not achieved, the athlete is then asked to perform the test with a 2x6 block under their heels. *(Figures 1-4)*

Tips for Testing:

- When in doubt, score the subject low.
- Try not to interpret the score while testing.
- Make sure if you have a question to view individual from the side.

Clinical Implications for Deep Squat

The ability to perform the deep squat requires closed-kinetic chain dorsiflexion of the ankles, flexion of the knees and hips, extension of the thoracic spine, and flexion and abduction of the shoulders.

Poor performance of this test can be the result of several factors. Limited mobility in the upper torso can be attributed to poor glenohumeral and thoracic spine mobility. Limited mobility in the lower extremity including poor closed-kinetic chain dorsiflexion of the ankles or poor flexion of the hips may also cause poor test performance.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements. Previous testing has identified that when an athlete achieves a score of II, minor limitations most often exist either with closed-kinetic chain dorsiflexion of the ankle or extension of the thoracic spine. When an athlete achieves a score of I or less, gross limitations may exist with the motions just mentioned, as well as flexion of the hip.

III

- Upper torso is parallel with tibia or toward vertical
- Femur below horizontal
- Knees are aligned over feet
- Dowel aligned over feet

Figure 1. ***Deep squat anterior view.***

Figure 2. ***Deep squat lateral view.***

Figure 3. ***Deep squat anterior view.***

II

- Upper torso is parallel with tibia or toward vertical
- Femur is below horizontal
- Knees are aligned over feet
- Dowel is aligned over feet
- 2x6 board required under feet

Figure 4. ***Deep squat anterior view.***

I

- Tibia and upper torso are not parallel
- Femur is not below horizontal
- Knees are not aligned over feet
- Lumbar flexion is noted
- 2x6 board required under feet

Hurdle Step

Purpose. The hurdle step is designed to challenge the body's proper stride mechanics during a stepping motion. The movement requires proper coordination and stability between the hips and torso during the stepping motion as well as single leg stance stability. The hurdle step assesses bilateral functional mobility and stability of the hips, knees, and ankles.

Description. The individual assumes the starting position by first placing the feet together and aligning the toes touching the base of the hurdle. The hurdle is then adjusted to the height of the athlete's tibial tuberosity. The dowel is positioned across the shoulders below the neck. The individual is then asked to step over the hurdle and touch their heel to the floor while maintaining the stance leg in an extended position. The moving leg is then returned to the starting position. The hurdle step should be performed slowly and as many as three times bilaterally. If one repetition is completed bilaterally meeting the criteria provided, a III is given. *(Figures 5-8)*

Tips for Testing:

- Score the leg that is stepping over the hurdle
- Make sure the individual maintains a stable torso
- Tell individual not to lock knees of the stance limb during test
- Maintain proper alignment with the string and the tibial tuberosity
- When in doubt score subject low
- Do not try to interpret the score when testing

Clinical Implications for Hurdle Step

Performing the hurdle step test requires stance-leg stability of the ankle, knee, and hip as well as maximal closed-kinetic chain extension of the hip. The hurdle step also requires step-leg open-kinetic chain dorsiflexion of the ankle and flexion of the knee and hip. In addition, the athlete must also display adequate balance because the test imposes a need for dynamic stability.

Poor performance during this test can be the result of several factors. It may simply be due to poor stability of the stance leg or poor mobility of the step leg. Imposing maximal hip flexion of one leg while maintaining hip extension of the opposite leg requires the athlete to demonstrate relative bilateral, asymmetric hip mobility.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements of the joints as well as muscular flexibility tests such as Thomas test or Kendall's test for hip flexor tightness.[24] Previous testing has identified that when an athlete achieves a score of II, minor limitations most often exist with ankle dorsiflexion and hip flexion with the step leg. When an athlete scores a I or less, relative asymmetric hip immobility may exist, secondary to an anterior tilted pelvis and poor trunk stability.

III

- Hips, knees and ankles remain aligned in the sagittal plane
- Minimal to no movement is noted in lumbar spine
- Dowel and string remain parallel

Figure 5. ***Hurdle step anterior view.***

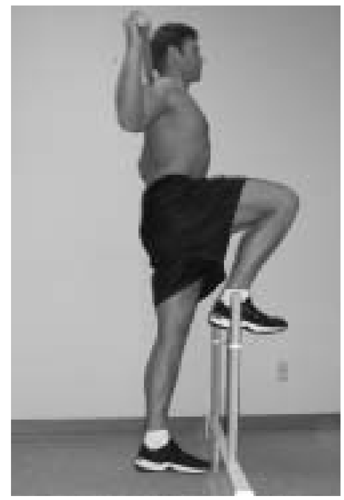

Figure 6. ***Hurdle step anterior view.***

Figure 7. ***Hurdle step anterior view.***

II

- Alignment is lost between hips, knees, and ankles
- Movement is noted in lumbar spine
- Dowel and string do not remain parallel

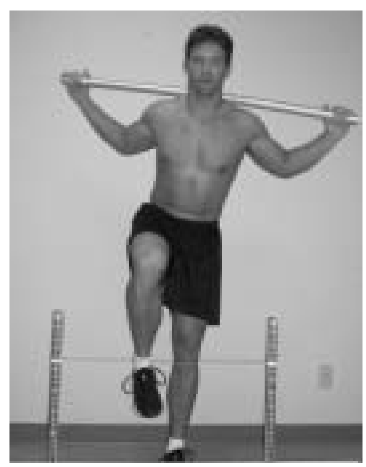

Figure 8. ***Hurdle step anterior view.***

I

- Contact between foot and string occurs
- Loss of balance is noted

In-Line Lunge

Purpose. The in-line lunge attempts to place the body in a position that will focus on the stresses as simulated during rotational, decelerating, and lateral type movements. The in-line lunge is a test that places the lower extremities in a scissor style position challenging the body's trunk and extremities to resist rotation and maintain proper alignment. This test assesses hip and ankle mobility and stability, quadriceps flexibility, and knee stability.

Description. The tester attains the individual's tibia length, by either measuring it from the floor to the tibial tuberosity or acquiring it from the height of the string during the hurdle step test. The individual is then asked to place the end of their heel on the end of the board or a tape measure taped to the floor. The previous tibia measurement is then applied from the end of the toes of the foot on the board and a mark is made. The dowel is placed behind the back touching the head, thoracic spine, and sacrum. The hand opposite to the front foot should be the hand grasping the dowel at the cervical spine. The other hand grasps the dowel at the lumbar spine. The individual then steps out on the board or tape measure on the floor placing the heel of the opposite foot at the indicated mark. The individual then lowers the back knee enough to touch the surface behind the heel of the front foot and then returns to starting position. The lunge is performed up to three times bilaterally in a slow controlled fashion. If one repetition is completed successfully then a three is given for that extremity (right or left). *(Figures 9-12)*

Tips for Testing:

- The front leg identifies the side being scored
- Dowel remains in contact with the head, thoracic spine, and sacrum during the lunge
- The front heel remains in contact with the surface and back heel touches surface when returning to starting position
- When in doubt score the subject low
- Watch for loss of balance
- Remain close to individual in case he/she has a loss of balance.

Clinical Implications for In-Line Lunge

The ability to perform the in-line lunge test requires stance leg stability of the ankle, knee, and hip as well as apparent closed kinetic-chain hip abduction. The in-line lunge also requires step-leg mobility of hip abduction, ankle dorsiflexion, and rectus femoris flexibility. The athlete must also display adequate balance due to the lateral stress imposed.

Poor performance during this test can be the result of several factors. First hip mobility may be inadequate in either the stance leg or the step leg. Second, the stance-leg knee or ankle may not have the required stability as the athlete performs the lunge. Finally, an imbalance between relative adductor weakness and abductor tightness in one or both hips may cause poor test performance. Limitations may also exist in the thoracic spine region which may inhibit the athlete from performing the test properly.

When an athlete achieves a score less than III, the limiting factor must be identified. Clinical documentation of these limitations can be obtained by using standard goniometric measurements of the joints as well as muscular flexibility tests such as Thomas test or Kendall's test for hip flexor tightness.[24]

Previous testing has identified that when an athlete achieves a score of II, minor limitations often exist with mobility of one or both hips. When an athlete scores a I or less, a relative asymmetry between stability and mobility may occur around one or both hips.

III

- Dowel contacts remain with lumbar spine extension
- No torso movement is noted
- Dowel and feet remain in sagittal plane
- Knee touches board behind heel of front foot

Figure 9. ***In Line Lunge anterior view.***

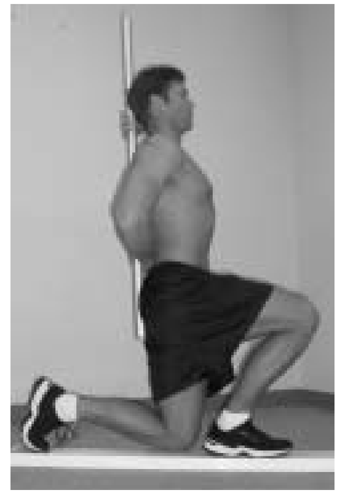

Figure 10. ***In Line Lunge lateral view.***

Figure 11. ***In Line Lunge lateral view.***

Figure 12. ***In Line Lunge anterior view.***

II

- Dowel contacts do not remain with lumbar spine extension
- Movement is noted in torso
- Dowel and feet do not remain in sagittal plane
- Knee does not touch behind heel of front foot

I

- Loss of balance is noted

SUMMARY

The research related to movement-based assessments is extremely limited, mainly because only a few movement-based quantitative assessment tests are being utilized. According to Battie et al,[23] the ultimate test of any pre-employment or pre-placement screening technique is its effectiveness in identifying individuals at the highest risk of injury. If the FMS™, or any similarly developed test, can identify at risk individuals, then prevention strategies can be instituted based on their scores. A proactive, functional training approach that decreases injury through improved performance efficiency will enhance overall wellness and productivity in many active populations. {The next issue -Volume 1; Number 3, August, 2006 of *NAJSPT* will provide the final four fundamental tests incorporated into the Functional Movement Screen (FMS)™.}

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The Functional Movement Screen™ is the registered trademark of FunctionalMovement.com with profits from the sale of these products going to Gray Cook and Lee Burton. The Editors of NAJSPT emphasize (and the authors concur) that the use of fundamental movements as an assessment of function is the important concept to be taken from Part I and Part II of this series and can be performed without the use of the trademarked equipment.

ORIGINAL RESEARCH

ELECTROMYOGRAPHY OF SELECTED SHOULDER MUSCULATURE DURING UN-WEIGHTED AND WEIGHTED PENDULUM EXERCISES

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ABSTRACT

Backround. Codman's pendulum exercises are commonly prescribed after shoulder surgery and injury to provide grade I and II distraction and oscillation resulting in decreased pain, increased flow of nutrients into the joint space, and early joint mobilization. Many shoulder protocols suggest that weight may be added to these pendulum exercises as rehabilitation progresses, however, very few guidelines exist to stipulate how much weight should be added.

Objectives. To determine if added weight affected the subject's ability to relax the shoulder musculature during pendulum exercises.

Methods. Twenty-six participants, ages 20 to 56 years old (mean 32.26, ± 8.51 years) were divided into two groups, nine pathological and 17 non-pathological. The muscle activity (EMG) of four variations of Codman's pendulum exercises 1) wrist suspended 1.5 kg weighted-ball, 2) hand-held 1.5 kg dumbbell, 3) hand-held 1.5 kg weighted-ball, and 4) no weight were recorded in each muscle.

Results. When grouped across all patients and all other factors included in the ANOVA, the type of pendulum exercise did not have a significant effect on shoulder EMG activity regardless of patient population or muscle tested. Generally, the supraspinatus/upper trapezius muscle activity was significantly higher than the deltoid and infraspinatus activity – especially in the patients with pathological shoulders

Conclusion. Performing the exercises with added weight did not result in significant increased shoulder EMG activity for the deltoid and infraspinatus muscles in subjects with and without shoulder pathology. However, patients with shoulder pathology had greater difficulty relaxing their supaspinatus/upper trapezius muscle group during Codman's pendulum exercises than healthy subjects.

Key Words: Codman, passive motion, distraction, muscle activity

INTRODUCTION

Early joint mobilization plays an important role in the rehabilitation of the injured shoulder for the return of normal kinematics and shoulder function.[1] Prolonged immobilization may predispose patients to muscle atrophy and poor neuromuscular control. The use of early joint motion can help prevent adhesions and contractures, especially pertaining to the periarticular connective tissue.[1-3] Passive range of motion is typically prescribed during postoperative care and early rehabilitation of the injured shoulder to initiate early joint motion.[3] The goal of an early rehabilitation protocol is to provide motion at the glenohumeral joint, while

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maintaining relative inactivity of the repaired or injured muscles and tendons. These goals also aim to minimize excessive tension at the suture line, or site of injury, and prevent adverse effects on already injured musculature.[1-6]

Codman's pendulum exercises are commonly prescribed after shoulder pathology to provide grade I and II distraction and oscillation resulting in decreased pain, increased flow of nutrients into the joint space, and early joint mobilization.[5,6] Shoulder protocols, as well as Codman[5] himself, suggest that weight may be added to these pendulum exercises as rehabilitation progresses, however, very few guidelines exist to stipulate when, and how much weight should be added.[6]

The use of a continuous passive motion device (CPM) is not always available or appropriate after a shoulder injury or surgery, but the replication of the motion without the activation of the injured or sutured muscles is crucial for safe rehabilitation of the injured or post surgical shoulder. Typically, patients after shoulder injury or surgery have a difficult time relaxing the shoulder musculature and performing Codman's pendulum exercises correctly. Dockery et al[2] evaluated the different rehabilitation protocols using electromyographic (EMG) analysis of the rotator cuff muscles to determine if different protocols promoted passive motion and how much rotator cuff activation occurred. Using a sample size of ten healthy volunteers, the authors tested various exercises commonly used postoperatively following shoulder surgery using surface electrodes. They concluded that therapist assisted exercises and Codman's pendulum exercises showed activity that was not significantly different from that of a CPM machine. The authors further concluded that these exercises are similar in safety to the CPM for obtaining early passive range of motion without disrupting the rotator cuff.

In a similar study, McCann et al1 used intramuscular fine wire EMG electrodes to examine shoulder muscle activity during passive, active, and resistive rehabilitation exercises. Passive exercises included Codman's pendulum exercises and EMG activity was categorized as: 1. minimal - if less than 20% of the muscle activity needed to raise a 2.25kg weight into abduction was elicited, 2. moderate - if 20%-50% of abduction activity was elicited, and 3. maximal - if greater than 50% was elicited. The results indicated that only the Codman's pendulum exercise demonstrated minimal muscle activity.

Very few studies have been conducted regarding this frequently used shoulder exercise during the early stages of rehabilitation. The purpose of this study was to determine if shoulder muscle activity increased with the addition of weight to Codman's pendulum exercises and if a difference was present in the muscle activation between the pathological shoulder and the healthy shoulder. Additionally, this study examined various methods of performing Codman's exercises and the effect on the activity of the shoulder musculature.

METHODS

Twenty six participants (14 females, 12 males), ages 20 ± to 56 years old (mean age 32.3 ± 8.5 years) were recruited. Upon review and approval by the Lenox Hill Hospital Institutional Review Board, informed consent was obtained from each participant. Interested volunteers were asked a series of questions in order to categorize the participants into either the pathological or non-pathological grouping. Nine participants who had pathological shoulders (mean age 39.3 ±12.5) and seventeen participants with non-pathological shoulders (mean age 30.4 ± 6.2) made up the two groups. Participants in the pathological group were classified as having a shoulder dysfunction and/or pain within the first 6 weeks of onset or were in their first 6 weeks postoperatively. The group of pathological shoulders consisted of two patients with superior labral anterior posterior repairs (SLAP), two with shoulder dislocations, one acromial clavicular joint (AC) decompression, one corococlavicular ligament reconstruction, one shoulder impingement, one post surgical capsular shift and acromioplasty, and one post-surgical thermal shrinkage. Participants in the non-pathological group were classified as anyone who did not have a shoulder dysfunction, surgery, or pain within the past year.

Surface electrodes were positioned on the supraspinatus/upper trapezius, infraspinatus, and middle deltoid following standard surface electrode placement.[7] The EMG sites were prepared according to standard protocol using a razor to remove hair, an alcohol pad to clean the skin, and an abrasive pad to abrade the skin.[8] Two surface electrodes were placed 2.54cm (1 inch) apart on each of the targeted muscles to prevent the electrodes from touching with motion. The placement of the electrodes was determined by referencing the work of the Delagi and Perotto.[7] The infraspinatus electrode placement was the midway point of the spine of the scapula and measuring two finger widths posteriorly and inferiorly from the middle of the spine. The supraspinatus/upper trapezius electrode placement was determined by palpation of the middle portion of the spine of the scapula, then moving superiorly two finger widths in the supraspinatus fossa. The middle deltoid placement was halfway between the acromion and the deltoid tubercle. A ground electrode was placed on the olecranon process of the arm being tested. Muscle activity output was checked prior the initiation of testing by having the participant contract each muscle to ensure correct electrode placement.

The EMG signals were band pass filtered from 10 to 500 Hz and sampled at 1000 Hz, with a common-mode rejection ratio of 130 dB (Telemyo, Noraxon, Scottsdale, AZ). A maximum voluntary isometric contraction (MVIC) for each muscle was performed for normalizing muscle activity during the Codman exercises.[9,10] The MVIC was taken with the patient positioned in the standard manual muscle position for the best isolation of the targeted muscle.[11] Shoulder abduction for the deltoid and supraspinatus/ upper trapezius was recorded with the arm starting at the participants side, standing 30° away from a pillow held on the wall. The MVIC was recorded as the participant abducted the arm and pressed as hard as they could into a pillow against the wall. External rotation for the infraspinatus was recorded with the subject standing near a pillow held against a wall with elbow flexed to 90° and shoulder held in 0° abduction and maximally pushing the wrist outward into the wall externally rotating the arm. Participants in the pathological group were asked to perform the MVIC on the uninvolved shoulder to avoid complications with the increased muscle activity of the involved shoulder musculature, while participants in the non-pathological group were asked to perform the MVIC on the shoulder being tested.[12]

Figure 1. Pendulum exercise using suspended ball weight

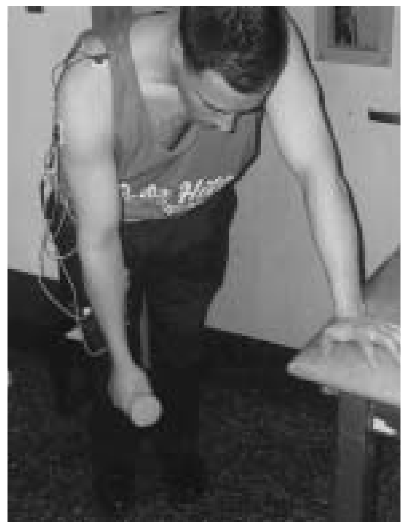

Figure 2. Pendulum exercise using hand-held dumbbell

Participants in both the pathological and non-pathological groups were instructed to perform four variations of Codman's pendulum exercises; Suspended ball weight of 1.5 kg (3.3 lbs) *(Figure 1)*, hand-held dumbbell of 1.5 kg *(Figure 2)*, hand-held ball weight of 1.5 kg *(Figure 3)*, and no weight *(Figure 4)*. The participant was randomly assigned an order of exercises.

Figure 3. Pendulum exercise using hand-held ball weight

Figure 4. Pendulum exercise unweighted

Participants were positioned with the non-tested arm resting on a table and the upper extremity to be tested hanging down for free movement. Trunk flexion at the hips was kept at a 75-degree angle from the upright vertical position as measured using a standard goniometer. The degree to which the trunk was flexed at the hips was modified from the traditional protocol of 90 degrees to allow for ground clearance of the suspended weight as it dangled from the arm. The "pendulum" or swinging motion was initiated by having the participant move their trunk slightly back and forth until motions of internal circumduction and then external circumduction were achieved. A circle was placed on the floor for guidance to control for the amount of circumduction that the participant would achieve during the testing. Shoulder range of motion limits were set to the minimum ability of the most involved shoulder pathology to avoid any possible complications. The speed of the arm swing was controlled for each participant using a loud beat on an electric metronome set at 40 beats per minute. Three trials for each parameter were performed to allow participants to become comfortable with the motion and the testing procedure. The third trial was used for data collection. Each participant performed five clockwise and five counter clockwise circles for each of the four parameters tested.

The EMG signals were acquired using the Noraxon TeleMyo telemetered EMG system (Noraxon USA, Scottsdale, AZ). The signals were low pass filtered at 500 Hz and high pass filtered at 10Hz. The EMG readings were sampled at 1kHz and analyzed using Noraxon Myosoft software. A 100ms moving average RMS function was applied to the raw EMG signal. The average RMS for the duration of the trial was computed by integrating the RMS and dividing the area by the time, thereby, producing the average amplitude. This process was conducted for all activity during the last trial and expressed as a percent of that particular muscle's MVIC. Internal and external circumduction were calculated for the non-pathological group since both arms were tested (i.e., left shoulder internal circumduction compared to right arm external circumduction). Internal and external circumduction were also calculated for each arm individually for the non-pathological group to verify the related muscle firing pattern was not different. The pathological group did not require these calculations since only the contralateral arm was tested.

Data Analysis

The effect of the different types of Codman exercises on muscle activity was examined using a 4x3x2 (exercise type x shoulder muscle group x pathology group) mixed model analysis of variance (ANOVA) with Bonferroni corrections for pairwise comparisons. Separate exercise type vs pathological group ANOVAs were performed on each muscle separately to further examine the data. Greenhouse-Geisser corrections were applied to significant ANOVAs that did not meet Mauchly's sphericity assumption in order to reduce the likelihood of a type I error. An alpha of 0.05 was set a priori.

RESULTS

When grouped across all patients and all other factors included in the ANOVA, the type of pendulum exercise did not have a significant effect on shoulder EMG activity regardless of patient population or muscle tested (effect of exercise type - $p=0.79$, exercise type by shoulder muscle interaction - $p=0.72$). Generally, supraspinatus/upper trapezius muscle activity (17% MVIC) was significantly higher than deltoid (6%) and infraspinatus activity (7%) (muscle effect – $p=0.001$).

When each muscle was analyzed separately for the effect of added weight distraction during Codman's pendulum exercises (comparing the three weighted conditions to the non-weighted condition), no significant increase in shoulder muscle activity occurred for any of the weighted conditions in the infraspinatus *(Figure 5; $p=0.39$)*, supraspinatus/upper trapezius *(Figure 6; $p=0.36$)* and two of the exercise conditions for the deltoid. However, deltoid activity was increased during the pendulum exercise with a dumbbell *(Figure 7; $p=0.04$)*.

Further analysis indicated that the pathological group had significantly greater muscle activity in the infraspinatus *(Figure 5; $p=0.041$)* and supraspinatus/upper trapezius *(Figure 6; $p=0.03$)* compared with the non-pathology group. No such significant difference between the pathological and non-pathological groups occurred in the deltoid group *(Figure 7; $p=0.11$)*.

DISCUSSION

Passive shoulder motion is regarded as standard early rehabilitation in patients postoperatively, as well as patients not undergoing surgery. Early joint mobilization plays an important role in the rehabilitation of the patient with an injured shoulder for the return of normal kinematics and shoulder function.[1,2] Dockery et al[2] inves-

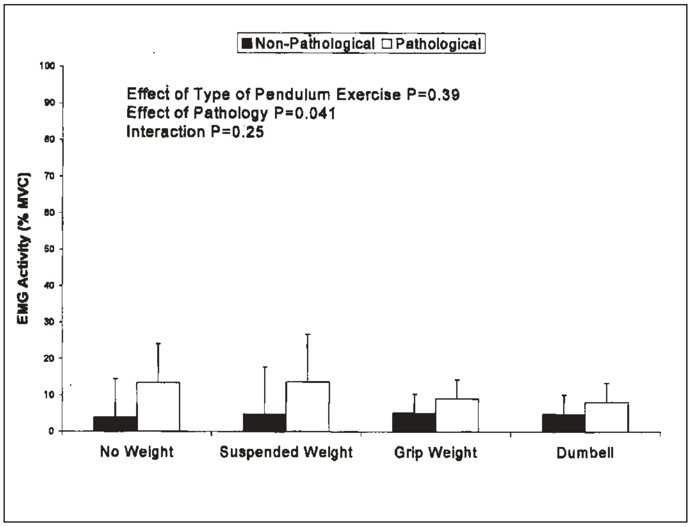

Figure 5. EMG activity for group with pathological and non-pathological shoulder expressed as percentage of MVIC for the infraspinatus

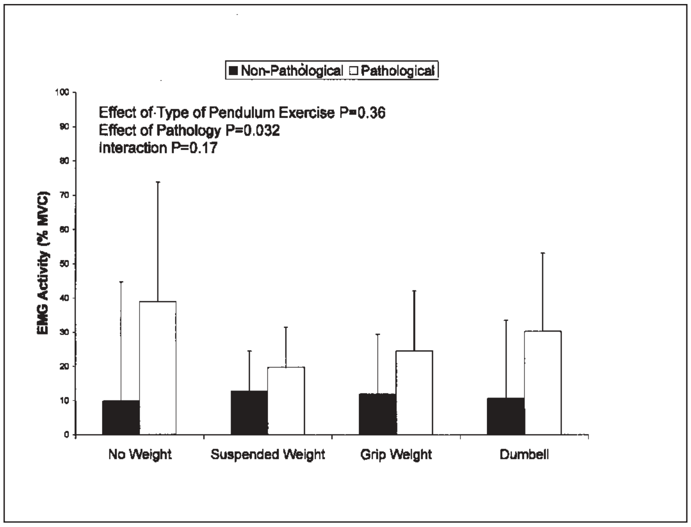

Figure 6. EMG activity for group with pathological and non-pathological shoulder expressed as percentage of MVIC for the supraspinatus/upper trapezius

tigated the different shoulder rehabilitation protocols using surface EMG analysis of the rotator cuff muscles to determine how much rotator cuff activity the protocols promoted. The authors concluded that shoulder muscle activity during Codman's pendulum exercises was not significantly different from that of a continuous passive motion (CPM) machine. The study conducted by Dockery et al2 used similar methodology (including the use of surface EMG) and found similar results as this present study.

In a similar study, McCann et al[1] used intramuscular fine wire EMG electrodes to examine shoulder muscle activity during passive, active, and resistive rehabilitation exercises. Only the pendulum exercise consistently showed minimal shoulder muscle activity defined as eliciting less than 20% of the muscle activity needed to raise a 2.25kg weight in abduction. The results of the present study are in agreement with the study of McCann et al,[1] indicating that the type of pendulum exercise minimally effects shoulder muscle activity. A small increase in deltoid activity occurred in the group with shoulder pathology compared to the group without pathology during the pendulum exercise performed with the dumbbell but the infraspinatus and supraspinatus/upper trapezius did not show a similar effect. In comparing the pendulum exercises within each muscle with no weight to the three pendulum exercises performed with weight it was apparent that the added distraction force by the addition of weight did not increase shoulder muscle activity. All muscle activity – for each type of exercise and for pathological and non-pathological shoulders exercise - was less than 20% MVIC except for the supraspinatus/upper trapezius in the pathological group. Therefore, the majority of the Codman's pendulum exercise for early shoulder rehabilitation fell below the minimal category established by McCann et al.[1]

The other clinically relevant finding was that the supraspinatus/upper trapezius and infraspinatus muscle activity were significantly higher in the group with shoulder pathology compared to the group without pathology. However, although a significant difference was found between the group with pathology and the group without pathology for the infraspinatus muscles, the percent of muscle activity was below 15% for all types of exercise in both groups. Therefore, the infraspinatus muscle appears to be able to relax during pendulum exercises.

The only muscle group that appeared to be unable to relax during the pendulum exercises was the supraspinatus/upper trapezius. The magnitude of muscle activity in the group with shoulder pathology indicated that these subjects were not able to sufficiently relax their supraspinatus/upper trapezius muscle. Mean supraspinatus/upper trapezius activity was 39% MVIC for the pendulum exercise performed without a weight, 20% when performed with a suspended weight, 25% when

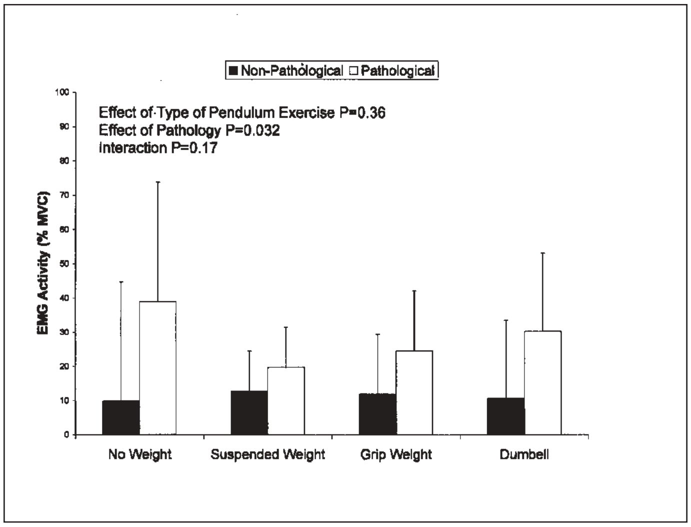

Figure 7. EMG activity for group with pathological and non-pathological shoulder expressed as percentage of MVIC for the deltoid

performed with a grip weight, and 30% when performed with a dumbbell. Corresponding values in the group without pathology were 10%, 13%, 12%, and 11% *(Table 1)*. This response may reflect a guarding response in patients with pathology. Biofeedback training may be necessary to facilitate relaxation in the supraspinatus/upper trapezius muscles during the pendulum exercises.

Since the results of this present study were largely negative with respect to the effect added weight on muscle relaxation it is important to assess whether this effect might have been subject to a type II error. Therefore, post hoc analyses were performed to determine the magnitude of difference in EMG activity that could be detected as significant ($p < 0.05$) with 80% power. Based on the standard deviation of the difference in EMG activity (% MVIC) between the different types of pendulum exercises these detection thresholds were 5% for the supraspinatus/upper trapezius and 2.5% for the infraspinatus and deltoid. These analyses indicate that there was sufficient power to detect clinically relevant differences in EMG activity between the different types of pendulum exercises.

Limitations of the study include use of surface EMG to measure muscle activity, especially in the supraspinatus muscle. To say that the muscle activity of the supraspinatus was isolated without interference from the upper trapezius and possibly the posterior deltoid is problematic. Therefore, the category of supraspinatus/upper trapezius was used. Despite this limitation, we believe that this study still provides valuable information related to muscle activity during the performance of Codman's pendulum exercises when adding weight. An additional limitation was the sample size. A larger sample size, especially in the group with pathological shoulders, would have been nice to compare to the control group.

CONCLUSION

The results of this present study indicate that adding a 1.5kg weight had no significant impact on shoulder muscle activity (as demonstrated by EMG analysis) during pendulum exercises for the deltoid and infraspinatus muscles for subjects with or without shoulder pathology. However, the supraspinatus/upper trapezius muscle group was clearly not relaxed in patients with shoulder pathology during any of the pendulum exercise.

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ORIGINAL RESEARCH

TRUNK ROTATION STRENGTH AND ENDURANCE IN HEALTHY NORMALS AND ELITE MALE GOLFERS WITH AND WITHOUT LOW BACK PAIN

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John F. Horton, BPE, MSc[a]

ABSTRACT

Background. The relative importance and asymmetric loading of the trunk muscles in golf (slow rotation backswing followed by high velocity downswing) may cause side-to-side imbalances in axial rotation strength and endurance characteristics amongst elite players who frequently play and practice. Such imbalances may further be compounded by the presence of low back pain.

Objective. To establish and compare trunk rotation strength and endurance of healthy individuals who do not play golf and those that are highly skilled at the sport. Additionally, a smaller group of elite golfers with non-debilitating low back pain (LBP) were also evaluated and compared to their healthy counterparts.

Methods. Forty healthy non-golfing control subjects, 32 healthy elite golfers, and 7 golfers with LBP participated in this study. Bilateral trunk rotation strength and endurance was assessed using the Biodex System III Isokinetic Dynamometer with torso rotation attachment. Strength and endurance data was analyzed using 2-way ANOVA.

Results. No significant differences in peak torque were found within or between groups. However, golfers with LBP demonstrated significantly less endurance in the non-dominant direction (the follow-through of the golf swing) than either healthy group. No significant difference in endurance was found between the non-golfing controls and the healthy elite golfers.

Conclusions. Trunk rotation endurance in golfers with LBP might be more important than strength alone in the prevention and treatment of LBP. The results from this study provide useful information on possible risk factors associated with low back pain in golfers (decreased endurance) and allow for sport-specific clinical intervention strategies to be developed.

Key Words: spinal rotation, injury, golf

INTRODUCTION

The effective execution of the golf swing not only requires rapid movement of the extremities but also substantial strength and power of the trunk muscles. The torso rotates away from the target (to the right for a right handed player) at approximately 85 deg/sec on the backswing while the powerful downswing involves trunk velocities approaching 200 deg/sec.[1] Pink et al[2] demonstrated relatively high and constant activity in the abdominal oblique muscles throughout most parts of the golf swing of skilled amateur players. In a similar study using professional golfers, Watkins et al[3] measured muscle activity in the erector spinae, abdominal oblique, and rectus abdominis. These authors established that all trunk muscles were relatively active during the acceleration phase of the golf swing with the trail-side abdominal oblique muscles showing the highest level of activity.

Given the relative importance of the trunk muscles in golf, particularly in terms of generating powerful axial rotation on the downswing, repetitive play and practice might contribute to enhanced rotational strength and endurance amongst these athletes. Furthermore, this asymmetric pattern of trunk rotation during the golf swing (slow rotation

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backswing followed by high velocity downswing) may cause side-to-side imbalances in rotational strength and endurance characteristics amongst elite players who frequently play and practice. These potential imbalances may contribute to an increased susceptibility of developing low back pain. Lindsey and Horton[4] have shown side-to-side maximum trunk rotation flexibility imbalances in elite golfers with and without low back pain (LBP).

The authors of this study are aware of only six peer-reviewed, non golf-related research studies that have evaluated strength and endurance characteristics of the trunk muscles during axial rotation movements.[5-10] Three of these studies[5,6,9] have reported isokinetic trunk rotation strength measures, while the others attempted to assess trunk muscle characteristics with electromyography (EMG) during repeated trunk rotations. Five different studies have investigated strength and or endurance parameters during trunk flexion and extension motions.[11-15] A limitation of most of these studies was they used custom made equipment to collect data. Kumar[5] reported that the scarcity of data for trunk rotation is directly attributable to the lack of suitable, accurate, standardized, and affordable devices to permit such measurement. Consequently, gaps in the literature exist regarding trunk rotation strength and endurance capabilities in the general population. Furthermore, no previous studies have investigated trunk rotation strength and endurance in golfers.

Suter and Lindsay[16] compared static trunk extensor endurance and inhibition of the quadriceps in low handicap golfers with LBP and healthy age-matched controls who did not golf. The authors were unable to show any significant differences in static holding times or decline in the EMG median frequency between groups. However, golfers with the lowest trunk extensor endurance were found to have significant quadriceps muscle inhibition compared to golfers with higher trunk endurance. It was postulated the inhibition of the quadriceps might be a direct result of abnormal afferent input to the muscle due to irritation of the spinal structures which innervate that specific region. No such association was observed for the normal subjects.

Considering the role of trunk rotation during the golf swing and the possible relationship between trunk muscle strength and endurance and low back pain, the purposes of the proposed exploratory research project were the following: 1) To establish normative data by measuring trunk rotational strength and endurance in healthy individuals who do not play golf. 2) To measure trunk rotation strength and endurance in age-matched elite golfers without LBP. (Collection of this data would permit comparisons between non-golfing control subjects and healthy golfers. This would also establish whether the repetitive and asymmetric nature of the golf swing leads to side-to-side differences in trunk rotation strength and endurance.) 3) To measure trunk rotation strength and endurance in elite golfers with non-debilitating LBP to determine if these individuals have less rotation strength and endurance compared to healthy elite golfers.

Owing to the scarcity of data associated with isokinetic trunk rotation testing, a number of secondary purposes were also investigated. In particular, whether subjects' torque and work results were influenced by trunk rotation range of motion (ROM) or body weight. The reliability and technical error associated with isokinetic strength testing was also examined.

METHODS

Subject Recruitment

Healthy male volunteer subjects that did not play golf were recruited via mass e-mail advertisements to University of Calgary faculty, staff, and students. Advertisements were faxed to golf professionals in the Alberta Professional Golf Association to recruit male professional and elite amateur golfers with and without LBP. Advertisements were also faxed to physical therapy clinics in the Calgary area to recruit elite male golfers with LBP.

Potential subjects were initially asked to complete a screening questionnaire regarding history of LBP (location, duration, frequency, and treatment) and the effects of playing golf and practicing on LBP. Those individuals who had not played golf more than twice per year in the past 5 years and had not experienced LBP in the previous 12 months were considered to be *control normals*. Elite golfers were defined as those playing and practicing at least 50 times per year and carrying a sanctioned handicap of 10 or less. Elite golfers who "never" or "rarely" experienced pain in the lumbar region of their back after practicing or playing during the golf season prior to completion of the questionnaire were classified as *control* *golfers*. Those players who "always" or "often" experienced pain in the lumbar region of their back after practicing or playing during the season preceding the questionnaire were classified as *golfers with LBP*.

Individuals were excluded from participating in the study if they were older than 49 years of age or had previously undergone surgery or other medically invasive procedures (nerve blocks or ablation, prolotherapy, cortisone injections) for LBP. Individuals over the age of 49 years were excluded based on published reports that both isometric and dynamic strength declines after age 50.[17] Furthermore, potential *golfers with LBP* were excluded if they had experienced golf-related LBP for less than six months prior to the commencement of the study. Those *golfers with LBP* who met the inclusion criteria were individuals who had experienced LBP for some time and continued to play golf in spite of this pain. These inclusion criteria restrictions made it more difficult to recruit eligible subjects resulting in a lower sample than in the other groups.

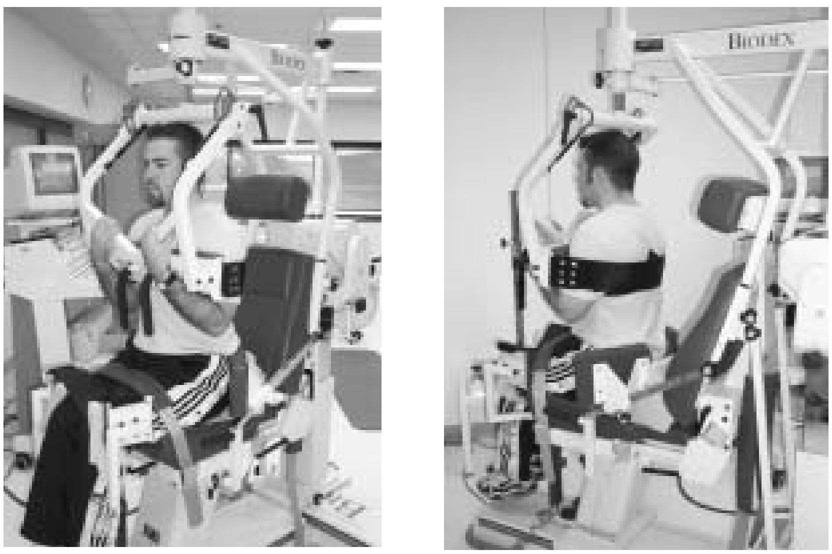

Figure 1. Subject positioning in the Biodex Torso Rotation Attachment.

Subjects

Forty healthy *control normals* (27.9 ± 4.8 yrs; 78.1 ± 8.2 kg; 176.5 ± 5.4 cm), 32 *control golfers* (30.0 ± 6.0 yrs; 79.1 ± 8.8 kg; 176.0 ± 5.7 cm), and 7 *golfers with LBP* (33.3 ± 9.6 yrs; 83.4 ± 10.9 kg; 178.7 ± 5.4 cm) participated in this study. All subjects completed a physical activity readiness questionnaire (PAR-Q) and signed an informed consent form prior to any testing procedures. Ethical approval was granted by the University of Calgary's Faculty of Medicine Conjoint Health Research Ethics Board.

Testing Procedures

Subjects were required to visit the University of Calgary Sport Medicine Centre on one occasion for testing. Prior to any testing procedures, subjects completed a low back pain and disability questionnaire (Oswestery Pain Questionnaire). Height and weight measurements were made followed by a short five-minute warm-up on a stationary bicycle. Following the warm-up, subjects were required to perform a series of standard stretches for the abdominal, back, hip, and leg muscles. An explanation of the testing procedures was then given verbally. Subjects were asked to sit in the chair of the Biodex System III Isokinetic Torso Rotation Attachment (Biodex Medical Systems, Inc., Shirley, New York) in an upright position so that the axis of rotation of the Torso Rotation Attachment was aligned with the long axis of the subject's spine *(Figure 1)*. Once adjustments to the Torso Rotation Attachment were made to suit each individual, leg straps and hip pads were tightened to restrict lower body movement. A strap was then tightened around the back so the upper body was as tight as possible against the chest pad without causing discomfort. Once the apparatus was properly adjusted, subjects were given an opportunity to perform slow practice repetitions of trunk rotation to become familiar with the desired movement. All subjects were experiencing minimal or no low back pain on the day of testing. Subjects then underwent isokinetic axial rotation strength and endurance testing as per the following consistent protocol:

Strength Testing

Subjects were initially asked to turn as far as possible (without discomfort) in both directions to determine total ROM and to set limits in right and left rotation. After setting the ROM limits, subjects were required to perform practice repetitions at 90 deg/sec at a moderate intensity to become accustomed to the required speed of movement for the strength test. Shortly after this, subjects performed five bilateral concentric trunk rotations at 90 deg/sec. Ninety degrees per second has been shown to be highly reliable for strength testing using the Biodex Isokinetic Dynamometer.[18] Subjects were instructed to concentrate on using the trunk muscles rather than the arms or shoulders to perform the axial rotation movements; to start with moderate effort rotations; to gradually increase their effort so the last three repetitions were of maximal effort; to give equal effort in both directions of rotation; to keep breathing throughout the test (each subject determined their own pattern of breathing); and to stop the test if they felt any discomfort. All subjects were given verbal encouragement during the test.

Endurance Testing

Subjects were given a five-minute rest period between the strength and endurance tests. Five minutes is regarded as adequate time for replenishment of ATP and phosphocreatine stores in muscle following short-term maximal exercise.[19] Range of motion limits were again set in the same manner as the strength testing protocol. Subjects were then required to perform moderate effort practice trunk rotations at a speed of 180 deg/sec. Following the practice repetitions and a brief rest, subjects performed 25 bilateral maximal trunk rotations at the 180 deg/sec speed. This velocity approximates the trunk rotation velocities reported for adult golfers[20] and is an accepted velocity for endurance testing with isokinetic dynamometers.[21] Subjects were instructed to perform the endurance test beginning with maximal effort and to maintain that intensity as long as possible throughout the duration of the test until 25 repetitions were completed. Subjects were given verbal encouragement throughout the test.

Strength Test Reliability

In addition to the strength and endurance testing for this research study, reliability of the strength test was assessed with a sub-group of 12 *control normal* subjects. These subjects performed the strength test three times with a 5-minute rest between tests. These same subjects repeated the same testing procedure 3-5 days following the initial testing session.

Data Analysis

To allow data from both left and right-handed subjects to be collected and interpreted in a consistent manner, right and left rotation values were categorized as "dominant" or "non-dominant." Right torso rotation for a right-handed subject was categorized as "dominant" rotation while left rotation was referred to as "non-dominant" rotation. Right rotation for a left handed subject was categorized as "non-dominant" rotation.

Strength Test Reliability

Repeated measures analysis of variance (ANOVA) was used to determine significant differences between the six strength tests, while test-retest reliability was assessed by intraclass correlation coefficients (ICCs) as described by Baumgartner.[22] A Technical Error Measurement (TEM) was also used to determine error of method due to biological and technical factors as per the following equation:

$$Absolute\ TEM = \sqrt{\frac{\sum di^2}{2n}}$$

Where d = The difference of one measure to the next; i = Number of individuals; 2n = number of samples x 2.

Rotational Strength Data

The peak torque of dominant and non-dominant trunk rotation during any of the test repetitions was used to represent trunk rotation strength. Peak torque (Nm) was calculated by the Biodex System III software and provided in a printout format. A 2-way ANOVA (groups X sides) was used to determine significant differences in strength measures between groups and between dominant and non-dominant sides.

Rotational Endurance Data

The total work (Joules) performed by subjects in both dominant and non-dominant trunk rotation over 25 repetitions was calculated by the Biodex System III software and provided in a printout format. A 2-way ANOVA (groups X sides) was used to determine significant differences in endurance measures between groups and between dominant and non-dominant sides.

Range of Motion of Torso Rotation

Total ROM (from dominant to non-dominant limit) was calculated by the Biodex System III software and provided in a printout format. An ASCI file for each subject was imported into Microsoft Excel to determine dominant ROM and non-dominant ROM.

Correlation Analyses

The ROM and strength data from control normals and control golfers were combined (n = 72) to determine a potential association between the ROM achieved during the test procedure and peak torque (Nm) (whether individuals with higher ROM were able to generate more trunk rotation torque). A Pearson Product Correlation was performed to investigate an association between ROM and peak torque. This calculation was done independently for dominant and non-dominant rotation data. The ROM and endurance data were also treated in this same manner to determine a potential association between the ROM achieved during the test procedure and work performed (Joules) (i.e. whether individual's with higher ROM were able to perform more work in rotation).

Body weight data and rotational strength data from *control normals* and *control golfers* were combined (n = 72) and a Pearson Product Correlation performed to determine if there was an association between body weight (kg) and peak torque (Nm). This calculation was done independently for dominant and non-dominant data. The body weight and endurance data was also treated in this same manner to investigate a potential association between subject weight and the work performed (Joules).

RESULTS

Strength Test Reliability

Mean values (± SD) of the 12 subjects for each of the six strength tests are presented in Table 1. No significant differences in peak torque were found between the six strength tests for left or right rotation (p > 0.05). Intraclass correlation coefficients for both dominant and non-dominant rotation were found to be 0.93. The Technical Error of Measurement was found to be 7.70 (5.82%) for dominant rotation and 8.12 (6.01%) for non-dominant rotation.

Table 1. Strength test reliability data (mean ± SD).

	Axial Rotation Torque (Nm)					
	Initial Test Session			Follow-up Test Session		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Dominant Rotation (n=12)	135.5 ±26.1	135.1 ±29.6	128.7 ±26.5	132.1 ±27.1	130.4 ±25.8	132.3 ±26.6
Non-Dominant Rotation (n=12)	139.7 ±25.9	140.0 ±23.9	132.2 ±23.3	133.0 ±31.3	134.1 ±27.0	130.5 ±25.1

Rotational Strength Testing

No significant differences in peak torque for non-dominant rotation were found between groups (df = 2,76; F = 0.51; p = 0.6) *(Table 2)*. A significant difference between groups was found for dominant rotation (df = 2,76; F = 3.15; p = 0.048). However, using a Sheffé post hoc test, there was evidence that the *control normals* and *golfers with LBP* were different though this fell just outside statistical significance (p = 0.056). No significant differences in peak torque between dominant and non-dominant rotation were found within any group (*control normals*: df = 1,78; F = 0.30; p = 0.59; *control golfers*: df = 1,62; F = 1.30; p = 0.26; *golfers with LBP*: df = 1,12; F = 1.46; p = 0.25).

Table 2. Peak rotational torque (mean ± SD) of subjects in dominant and non-dominant rotation at 90 deg/sec.

	Peak Torque (Nm)	
	Non-Dominant Rotation*	Dominant Rotation
Control Normals (n=40)	141.4 ± 27.5	138.2 ± 24.8
Control Golfers (n=33)	138.8 ± 28.6	130.7 ± 28.4
Golfers with LBP (n=7)	129.8 ± 28.8	111.6 ± 27.7

** left trunk rotation in a right-hand dominant subject*

Rotational Endurance Testing

Significant differences in total work performed were found between groups for non-dominant ($df = 2,76$; $F = 5.49$; $p = 0.006$) but not dominant rotation ($df = 2,76$; $F = 2.78$; $p = 0.07$) *(Table 3)*. Using a Sheffé post hoc test, it was found that there were significant differences for non-dominant rotation between *control normals* and *golfers with LBP* ($p = 0.009$), and between *control golfers* and *golfers with LBP* ($p = 0.009$). No significant differences in total work were found between *control normals* and *control golfers* ($p = 0.99$). No significant differences in total work were found between dominant and non-dominant rotation in any group (*control normals*: $df = 1,78$; $F = 0.79$; $p = 0.38$; *control golfers*: $df = 1,62$; $F = 0.57$; $p = 0.45$; *golfers with LBP*: $df = 1,12$; $F = 0.2$; $p = 0.66$).

Table 3. Rotational endurance (mean ± SD) of subjects in dominant and non-dominant rotation at 180 deg/sec.

	Work (Joules)	
	Non-Dominant Rotation†	**Dominant Rotation**
Control Normals (n=40)	2908.1 ± 219.5	2797.0 ± 561.1
Control Golfers (n=33)	2922.6 ± 550.6	2817.2 ± 563.2
Golfers with LBP (n=7)	2203.1 ± 407.2	2294.9 ± 358.6

† *left trunk rotation in a right-hand dominant subject*

Association Between ROM and Torque and Work

A poor correlation was found between the amount of ROM and the amount of torque produced in both dominant ($r = -0.29$) and non-dominant rotation ($r = -0.17$). A poor correlation was also found between the amount of ROM and the amount of work performed in both dominant ($r = 0.16$) and non-dominant rotation ($r = 0.36$).

Association Between Body Weight and Torque and Work

A moderate correlation existed between bodyweight and the amount of torque produced in both dominant ($r = 0.44$) and non-dominant rotation ($r = 0.44$). A poor correlation was found between body weight and the amount of work performed in both dominant ($r = 0.34$) and non-dominant rotation ($r = 0.28$).

DISCUSSION

The resultant ICC of greater than 0.90 for the test-retest data collected from 12 control normals on two different days indicated that the strength and endurance test protocol used in the present study were reliable measures of peak torque. The Technical Error of Measurement indicates that approximately 6% of the measured values obtained from this method of data collection were potentially due to apparatus error (technical error) or other biological factors. This finding means that if the same device were used in a future intervention study, more than 10% change in performance would be necessary to determine a significant effect from the intervention.

One of the purposes of this study was to establish normative trunk rotation strength and endurance data in healthy individuals who do not play golf. This was necessary as there is very limited data available pertaining to axial rotation.[5-7,9] The studies by Kumar et al[5-7] investigating trunk rotation are difficult to reproduce since the measuring device used was developed in their laboratory. In comparison to other published trunk rotation strength data using commercially available equipment (Cybex II), the *control normal* values from the present study *(Table 2)* were slightly higher than the control values reported by Newton et al[9] *(Table 4)*. The *control normals* in the present study were predominantly obtained from an active University population and, therefore, may have had a more athletic background than the control subjects in the study by Newton et al.[9]

The results from Table 2 showed there were no significant differences in trunk rotation torque either between or within the *control normals* and *control golfers* groups. Although the original hypothesis that elite golfers would exhibit greater side-to-side differences than control subjects was not statistically supported, it was interesting to note that a slight and consistent trend in asymmetry was

Table 4. Strength testing data reprinted from Newton et al[9]

	Axial Rotation Torque (Nm)					
	Left Rotation			Right Rotation		
	60 deg/s	120 deg/s	150 deg/s	60 deg/s	120 deg/s	150 deg/s
Control Subjects (n=35)	127.4±42.0	117.9±39.3	115.2±35.3	127.4±35.3	119.3±37.9	117.9±36.6
Subjects with LBP (n=47)	89.5±39.3	85.4±40.7	86.8±37.9	87.6±36.6	82.7±39.3	86.8±39.3

noticed in both *control normals* and *control golfers*. In both groups, the non-dominant direction produced the higher values. A possible reason for slightly higher non-dominant rotation strength in *control normals* might be related to the many recreational activities that involve rotation to the non-dominant side (left trunk rotation for right-handed throw/swing in baseball or racquet sports). It was expected that the golfers would demonstrate an overall higher amount of trunk rotation strength as well as a more pronounced side-to-side difference than *control normals* due to the power and frequency that a highly skilled golfer would perform asymmetrical axial rotation motions. However, since powerful eccentric contractions on the dominant side are also required to decelerate the torso during the follow-through of a golf swing, it is possible these eccentric forces help facilitate concentric strength development of the same muscles.

An additional finding from Table 2 was that trunk rotation strength in *golfers with LBP* was lower, but not to a significant degree, than the values recorded from the *control normals* and *control golfers*. Although statistical significance was not observed, the lower strength values recorded from *golfers with LBP* might have clinical significance which could be related to LBP. It is not clear whether trunk muscle weakness causes LBP or whether LBP leads to muscle dysfunction and hence weakness. However, results from the back pain questionnaire administered prior to testing indicated that *golfers with LBP* were typically only affected by LBP after and not before golfing. Golf has been shown to create considerable shear and compressive loads on the lumbar spine.[23] It seems reasonable to suggest that golfers lacking trunk muscle strength may not be able to control these stresses as well as healthy golfers and thus be more likely to experience LBP when swinging the golf club.

The authors of this study were unable to locate any previously published normative data on isokinetic trunk rotation endurance. The findings from the current study showed no significant side-to-side differences in trunk rotation endurance between any of the groups *(Table 3)*. However, significant differences in rotational endurance were found between *control normals* and *golfers with LBP* and between *control golfers* and *golfers with LBP* in the non-dominant direction. Non-dominant rotation for a golfer (left rotation for a right handed player) occurs at great velocity as the player attempts to accelerate their body towards the target to create maximum clubhead speed. Since this powerful movement is repeated throughout the game or practice session, decreased endurance could lead to premature fatigue and increased injury risk to the trunk region The importance of trunk endurance in preventing LBP has been discussed by McGill[24] and appears to be supported by the results of this study. Furthermore Suter and Lindsay[16] found associations in a population of golfers between poor static trunk extensor endurance and increased quadriceps inhibition. Quadriceps inhibition was postulated to be reflective of irritation to the lumbar structures. Clinical ramifications from the present study suggest that muscular endurance exercises focusing on rotation of the trunk should be an important component of rehabilitation programs targeting golfers with LBP.

A secondary purpose of this study was to investigate whether trunk rotation ROM influenced the amount of torque and work produced by subjects. The relatively poor correlations indicate that ROM did not appear to influence the amount of torque and work performed by subjects. These findings may have interesting implications for the golf swing, particularly in terms of the amount of trunk rotation on the backswing and the subsequent clubhead speed developed on the downswing. The results from the present study seem to support findings by Neighbors[25] who was able to demonstrate that golfers could generate just as much clubhead velocity using a shortened backswing involving considerably less trunk rotation. Decreasing the amount of trunk rotation ROM during the golf swing has been suggested as important for reducing LBP in individuals that golf.[4,26]

Another secondary purpose was to investigate whether overall body weight influenced torque and work. Results showed that a moderate correlation existed between body weight and peak torque. These findings support those of Newton et al9 suggesting that rotational strength and endurance data can be presented in absolute terms (not normalized) when making between-subject comparisons.

Limitations

Limitations exist in the interpretation of the results from this study. It has been suggested that isokinetic performance does not provide a valid measure of actual muscle strength or deficit. Rather, isokinetic performance measures what patients are doing with their muscles in a controlled environment at pre-determined constant speeds and in isolated movement directions.[9] It is not known how accurately the test procedure incorporated in this study represents the trunk rotation performance associated with swinging a golf club.

The validity of the extrapolation of results from a cross-sectional study is very dependent on the representativeness of the sample. An inherent limitation of most observational studies is that the sample is not representative of the population. The strict inclusion criteria made it more difficult to recruit elite golfers with LBP. The relatively low number of subjects in the *golfers with LBP* group makes true associations less clear than would have been observed with a larger subject pool. Another limitation of cross-sectional studies is determining cause or effect. This study did not permit conclusions about the cause or effect relationship between trunk rotation strength and endurance and LBP.

Future studies should establish normative data for different samples than 18 to 49 year old males (females, seniors). Eccentric trunk rotation strength and endurance parameters should also be investigated considering the important deceleration role this type of contraction plays in the golf swing. Furthermore, it would be worthwhile to conduct a prospective study with an exercise intervention to improve trunk rotation strength and endurance in golfers with LBP with the goal to decrease pain symptoms. Similarly, an exercise intervention could be implemented to increase trunk rotation strength and endurance in healthy golfers to investigate the effects on performance (clubhead speed).

CONCLUSIONS

Normative trunk rotation strength and endurance measures were established with the Biodex System III Isokinetic Dynamometer. As well, this study was the first to investigate isokinetic trunk rotation of elite male golfers with and without LBP. The hypothesis that elite golfers (*control golfers*) would exhibit greater overall strength and endurance as well as increased side-to-side differences compared to healthy control subjects (*control normals*) was not supported in this case.

The hypothesis that elite golfers with LBP (*golfers with LBP*) would demonstrate less rotational strength than *control golfers* was not supported, however, *golfers with LBP* did display significantly less torso rotation endurance in the non-dominant, or downswing direction, than *control golfers*. Trunk rotation endurance in golfers with LBP might be more important than strength alone in the prevention and treatment of LBP.

Another important finding from this study was that ROM used during the test did not appear to influence the amount of torque or work performed. This finding suggests that golfers may not need to employ maximum trunk rotation ROM on the backswing to generate a powerful downswing. Furthermore, the results support those of Newton et al[9] suggesting that rotational strength and endurance data can be presented in absolute terms (not normalized) when making between-subject comparisons.

The importance of this study in establishing trunk rotation normative data is considerable especially when taking into account the immense popularity of the sport and high incidence of low back problems. The results from this study provide valuable information on possible risk factors associated with low back pain in golfers (decreased endurance) and allow for intervention strategies to be developed. Future studies should prospectively investigate the cause and effect relationships between LBP and trunk muscle function.

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