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ORIGINAL RESEARCH

AN ANALYSIS OF PEAK PELVIS ROTATION SPEED, GLUTEUS MAXIMUS AND MEDIUS STRENGTH IN HIGH VERSUS LOW HANDICAP GOLFERS DURING THE GOLF SWING

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ABSTRACT

Purpose/Hypothesis: The kinematic sequence of the golf swing is an established principle that occurs in a proximal-to-distal pattern with power generation beginning with rotation of the pelvis. Few studies have correlated the influence of peak pelvis rotation to the skill level of the golfer. Furthermore, minimal research exists on the strength of the gluteal musculature and their ability to generate power during the swing. The purpose of this study was to explore the relationship between peak pelvis rotation, gluteus medius and gluteus maximus strength, and a golfer's handicap.

Subjects: 56 healthy subjects.

Material/Methods: Each subject was assessed using a hand-held dynamometry device per standardized protocol to determine gluteus maximus and medius strength. The K-vest was placed on the subject with electromagnetic sensors at the pelvis, upper torso, and gloved lead hand to measure the rotational speed at each segment in degrees/second. After K-vest calibration and 5 practice swings, each subject hit 5 golf balls during which time, the sensors measured pelvic rotation speed.

Results: A one-way ANOVA was performed to determine the relationships between peak pelvis rotation, gluteus medius and gluteus maximus strength, and golf handicap. A significant difference was found between the following dependent variables and golf handicap: peak pelvis rotation ($p = 0.000$), gluteus medius strength ($p = 0.000$), and gluteus maximus strength ($p = 0.000$).

Conclusion: Golfers with a low handicap are more likely to have increased pelvis rotation speed as well as increased gluteus maximus and medius strength when compared to high handicap golfers.

Clinical Relevance: The relationships between increased peak pelvis rotation and gluteus maximus and medius strength in low handicap golfers may have implications in designing golf training programs. Further research needs to be conducted in order to further explore these relationships.

Key Words: golf, gluteus maximus, gluteus medius, peak pelvis rotation

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INTRODUCTION

The timeless subject of how to improve one's golf swing has been examined extensively.[1,2,3,4,5,7,8,9] Previous authors have investigated proximal to distal kinematics, coiling, and the efficiency of energy transfer through the principle of work, the x-factor, and rotational speed.[1,2,3,4,5,7,8]

Proximal to distal kinematic sequencing has been demonstrated in several rotational sports such as tennis, baseball, soccer and golf.[1,2,3,4,5,7,8,9] The sequence of the golf swing is proposed to occur in a proximal to distal pattern where "motion is initiated with the larger, heavier, slower central body segments; then, as the energy increases, the motion proceeds outward to the smaller, lighter and faster segments."[1(pg 247)] In the literature, proximal to distal sequencing may also be called kinetic linking or the kinematic sequence.[2] The latter, kinematic sequence, is the preferred term of Phil Cheetham, head biomechanist and director of the Titlist Performance Institute Biomechanics Advisory Board. Cheetham focuses on the transition and downswing phases of the golf swing when assessing kinematic sequence.[2,3,4,5]

The transition phase of the golf swing occurs quickly and is the movement from backswing into downswing, during which each body segment changes direction.[2] In proper kinematic sequencing, the order of body segment change in direction should be as follows: pelvis, thorax, lead arm, and then club.[2,3,4,5] This occurs through the power of the leg muscles rotating the pelvis forward towards the target. The pelvis then accelerates, but quickly decelerates, transferring energy to the thorax.[5,6] This pattern is continued with an acceleration and deceleration of the thorax which transfers energy to the lead arm and finally to the club.[5] This order should continue throughout the downswing, during which all body segments are accelerating and decelerating with specific timing to bring the club to impact with the ball at maximum speed[2,3,4,5] (Figure 1). The kinematic sequence impacts energy transfer and power during the golf swing as well as compensation by other body parts.[2,6] If the kinematic sequence is out of order, not only can energy be lost; which then decreases speed, power, accuracy, and consistency, but other body segments can begin to compensate as well.[5,6]

It is important to analyze the kinematic sequence for optimal performance, and also to avoid injury. Cheetham has defined the golf swing as a delicate balance between successive postures and forces that must be developed in a coordinated sequence over a very short period of time.[3] The pelvis and spine are the central transfer point between the lower and upper body, and thus, are subject to an extreme amount of force during the golf swing.[3] Therefore, it is important for hip and pelvis rotation to occur in a smooth and coordinated fashion in order to avoid compensations for poor spine mechanics.[2]

Lephart indicated that following an exercise program mimicking the golf swing may improve the sequencing pattern of the pelvis, shoulders, and arms.[7] Although the primary purpose of their research and eight-week golf-specific exercise program was to increase physical fitness and improve swing mechanics and overall golf performance in recreational golfers, the researchers also found improvements in swing kinematics.[7] They attributed the enhanced kinematic sequence to "motor learning effects and improvements in physical characteristics specific to golf."[7(pg. 866)] As a result, the researchers suggested that the improved sequencing pattern may have had an impact on the greater efficiency in power transfer to the club and ball exhibited by some of the subjects.[7]

The coiling principle, another theory of kinematic sequencing, is currently utilized by many golf pros.[8] Coiling seeks to create torso-pelvic separation by maximizing upper torso rotation and minimizing pelvic rotation during the backswing.[8] Steven Nesbit, a mechanical engineering professor, used the principles of physics to discover that during the golf swing the body is synonymous with a spring or coil, acting in a way that ultimately increases ball velocity and driving distance.[9] A centrifugal force is created by the upper body coiling around the pelvis.[10] The axis of rotation is fixed around the spine.[10] As the upper body coils around the pelvis, the potential energy increases.[9] The energy transferred from each body segment during the downswing becomes greater in magnitude as the energy progresses to further distal body segments.[9] The sequencing of increased kinetic energy follows the pattern of the legs, hips, low back, upper back, shoulders, arms, and wrists.[9] Nesbit and Serrano also found that the generation of power during the back swing comes primarily from the spine and hip joints.[9] This coiling pattern is seen in most pro golfers as it is essential in generating power during the golf swing.

A more recent development in kinematic sequencing in golf called the "X-factor" is used to describe the rotation of shoulders with relation to hips at the top of the golf swing.[4] Studies have shown that an increase in upper-torso rotational velocity and an increase in the X-factor have the potential to increase club head velocity, which in turn will increase the carrying distance of the ball as long as the rest of the swing mechanics are timed correctly.[4,7]

Most studies on the X-factor have not considered the events that occur after the club progresses into the downswing phase; however, one study by Cheetham et al has addressed this. Cheetham et al compared the X-factor at the top of the backswing and early downswing between highly skilled and less skilled golfers. They found that although the X-factor was not significantly larger in highly skilled golfers at the top of the backswing, it was significantly larger in early downswing.[4]

Highly skilled golfers have a stretch which inhibits the X-factor from rapidly closing during downswing.[4] This X-factor stretch is the amount of separation between the shoulders and the hips at the beginning of the downswing. Cheetham showed that less skilled players tend to have very little separation between their hips and shoulders, and they tend to rotate towards the target at the same time.[4] Highly skilled players are more inclined to rotate their hips significantly faster during the early downswing causing the muscles of the torso to stretch.[4] The pelvis of highly skilled golfers also had a higher rotational velocity which caused an increase in the X-factor. It is thought that "a rapid rotation of the pelvis in early downswing may trigger sensitive stretch receptors in muscles to quickly shorten" [(pg 9)] thus creating a more forceful contraction to drive the ball.[4] Due to the stretch between the shoulders and the torso at the top of the backswing there is a storage of elastic energy in the torso which is then released resulting in a stronger contraction.[4] Ultimately, the authors of this study concluded that the X-factor stretch, not the X-factor proposed by earlier research, causes an increase in force production during the downswing which in turn increases the club head speed at impact.[4]

The concepts of the kinematic sequence, coiling, and the X-factor stretch have proven to be very useful in golf swing analysis.[1,2,3,4,5,7,9] The rotation of the pelvis initiates the kinematic sequence as well as plays a vital role in creating power during the X-factor stretch.[1,2,3,4,5,7] Peak pelvis rotation velocity was included in Cheetham's study which compared the kinematic sequence parameters between amateur and professional golfers.[3] The professional golfers had an average peak pelvic rotation velocity of 477 $\pm$ 53 degrees/second while the mean for the amateurs was only 395 $\pm$ 53 degrees/second.[3] These results indicated that a significant difference ($p = 0.011$) existed in peak pelvis rotation velocity between golfers of two skill levels.[3] Cheetham proposed that ideally a 1.5 transfer ratio should exist between the pelvis to thorax and thorax to arm. A slightly higher transfer ratio of 2.2-2.4 is optimal for the transfer of energy between the lead arm to club.[2] In other words, each segment should increase in speed (degrees/sec) to 150% of the proximal connecting segment.[2] Assuming that this transfer ratio holds true, it is easy to see how an increase in peak pelvic rotation can greatly increase club head speed and in turn, power.

Building on Cheetham's research, a more thorough understanding of peak pelvis rotation and its role in golf is needed. The purpose of this research was to determine if there was a difference in peak pelvis rotation speed between high and low handicap golfers. A secondary purpose was to determine if there was a significant difference in gluteus maximus and gluteus medius strength between high and low handicap golfers. Based on the purposes of this study, it was hypothesized that peak pelvis rotation speed would be significantly faster and gluteus maximus and gluteus medius strength would be significantly higher in low handicap golfers when compared to high handicap golfers.

METHODS

The subject pool included volunteer participants from the current PGA and LPGA tour, Belmont University's golf teams, recreational golfers, and non-golfers. Every subject was provided with an informed consent document. The subjects that participated in the study were asked a series of questions regarding his/her golf handicap. The subjects were then assigned to a high handicap group ($\geq$18; $N = 18$) or low handicap (< 5; $N = 38$) group. Those with a handicap between 6 and 17 were excluded from the study. The subjects that reported being new to golf and did not have USGA handicap were assumed to have a

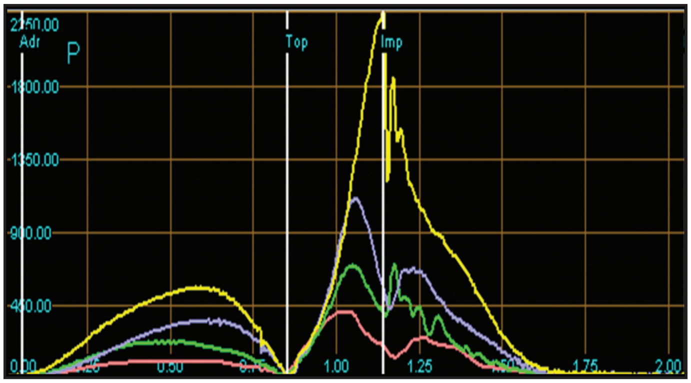

Figure 1. *This graph shows an example of an optimal kinematic sequence during a golf swing. This generic sequence was measured by 3-D motion analysis, which provides outputs nearly identical to those from the K-Vest. The horizontal axis represents time from address (Adr) to the top of the backswing (Top) to ball impact (Imp) to finish. Rotation speed in degrees per second is shown on the vertical axis. This graph shows proper kinematic sequencing with the pelvis (pink) achieving its top speed first, followed by the trunk (green), arms (purple), and finally the club (yellow). Once each segment peaks, an immediate and smooth deceleration of that segment occurs which illustrates an effective and efficient transfer of energy between segments.*

handicap ≥18. Those that had an injury or health restrictions at the time of the study were also excluded. After the paperwork and inclusion/exclusion criteria were determined, each subject participated in a lower quarter screen including a functional movement assessment as well as dermatome and myotome testing in order to screen for injury. All subjects passed the screen to rule out injury. After the screening, manual muscle testing was performed on each individual with a hand held dynamometer (Nicholas Manual Muscle Tester, Lafayette Instruments, Lafayette, IN). Manual muscle testing was performed using the standard protocols and positions for gluteus maximus and gluteus medius on the right and left side (Figure 2). Results of the manual muscle tests were normalized to body weight for each subject. Next, each subject was given a golf specific warm-up session (Table 1). The K-vest was then placed on the subject and calibrated. Each subject was allowed 5 practice swings using a 7 or 8 iron. The subject then took 5 test swings while the K-vest software collected and recorded the data of each swing. The subjects' average peak pelvis rotation speed was calculated from the 5 swings.

INSTRUMENTATION

The K-vest (Bentley Kinematics, Exton, PA) is a motion analysis system that was designed specifically for golf. The system includes 3 wireless motion tracking sensors (each weighing less than 2 ounces), hip and shoulder garments, a receiver, and software (video camera and laptop are not included).[11] The 3 sensors were placed on different parts of the body: the hip sensor was centered on the back of the sacrum, and was secured in place by the hip garment; the shoulder sensor was placed in between the shoulder blades between spinal levels T3-T5, secured by the shoulder garment; and the wrist sensor was attached to the player's golf glove of the lead wrist (see Figure 3).[11] Each individual sensor is composed of a bundle of 9 smaller sensors, which allow for measurement of the golf swing in 3 dimensions.[11] The measurements and data were transmitted to a laptop with the K-vest software, through which real-time video was analyzed.[11] The technology of K-vest software is backed by the Titlelist Performance Institute (TPI) 3D algorithms and included the TPI 3D

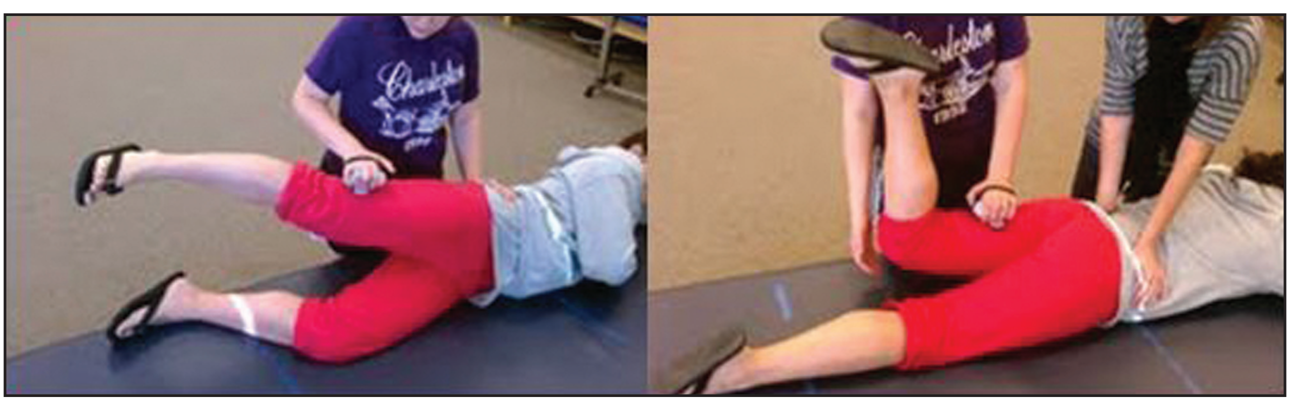

Figure 2. *Standard positioning for manual muscle testing of gluteus maximus and gluteus medius.*

Table 1. *Golf Specific Warm-up.*

Arm Circles	• Raise arms out to side • Start with small circles with hands and gradually increase • Hands should feel light • After 15 seconds switch directions and repeat • Complete each direction twice
Overhead Extension	• Grab club just outside shoulder width • Hold club over head with arms extended • Feet shoulder width apart • Bring club down to legs and raise again • Repeat movement for 15 seconds
Overhead Sidebend	• Grab club just outside shoulder width • Feet shoulder width apart • Hold club extended overhead • Lean body to one side feeling stretch on opposite side • Hold for brief moment and go immediately to other side and repeat • Repeat each side 3 times each
Golf Rotations	• Place club over shoulders behind neck • Grab at each end of club • Assume golf posture and rotate upper body back and through • Keep lower body quite still and feel the stretch in mid section • Repeat each side 10 times
Modified Good Mornings	• Slightly flexed knees • Grab club and bend at hips • Let arms hang relaxed in front of legs • Stretch hamstrings and lower back by lowering club down legs • Return to starting position and repeat 15 times
Partial Squats	• Feet shoulder width apart • Place club in front of you and hold with both hands for balance • Lower body by bending at the knees not hips • Raise back up and repeat 15 times • Keep upper body very erect
Side Lunge	• Hold club behind neck, looking straight ahead • Step directly out to one side feeling a little pull up inside of leg • Repeat to the other direction • Alternate directions each time • Repeat 10 times each side

software.[11] Reliability and validity have been assessed and found to be comparable to the gold standard motion analysis video capture methods, and the US Military has employed the K-vest for training and research due to the extraordinary accuracy and durability of the K-sensors.[11] The research team was instructed on the use of the K-vest and its software by the developers. This system was used to calculate the peak pelvis rotational speed which was then correlated with the golfer's handicap.

RESULTS

Data Analysis

A one-way analysis of variance was performed to determine if there were significant differences between each variable and the two handicap groups ($p \le 0.05$).

Peak Pelvis Rotation Speed

The low handicap group had an average peak pelvis rotation speed of 503.21 d/s while the high handicap group had an average peak pelvis rotation speed of

Figure 3. *Subjects donned the K-vest equipment and were given 5 practice swings before data collection. The K-vest consists of 3 wireless motion tracking sensors: one on the sacrum, one between the scapulae and one on the glove of the lead wrist.*

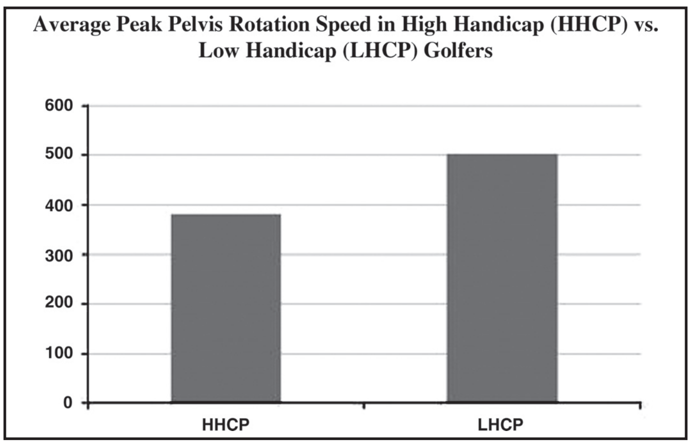

Figure 4. *Average Peak Pelvis Rotation Speed in High vs. Low Handicap Golfers.*

380.06 d/s (Figure 5 and Table 2). There was a significant difference ($p = 0.000$) in peak pelvis rotation speed between high handicap and low handicap groups (Figure 4).

Gluteus Maximus Strength

The dynamometer output was given in pounds which was then normalized as % of body weight for each of the subjects. The mean strength results for the low handicap group were: right gluteus maximus = 30.5%, left gluteus maximus = 30.6%. The average strengths of the high handicap group were: right gluteus maximus = 21.9%, left gluteus maximus = 20.7% (Table 2). There was a significant difference ($p = 0.000$) in gluteus maximus strength between high handicap and low handicap groups.

Gluteus Medius Strength

The mean strength of the low handicap group were: right gluteus medius = 30.5%, left gluteus medius = 30.2%. The average strengths of the high handicap group were: right gluteus medius = 22.6%, left gluteus medius = 22.4% (Table 2). There was a significant difference ($p = 0.000$) in gluteus medius

Table 2. *Average Peak Pelvis Rotation Speed and Gluteus Maximus and Medius Strengths of Low Handicap and High Handicap Subjects.*

Dependent Variables:	Low Handicap Group	High Handicap Group
Peak Pelvis Rotation Speed	503.21 d/s	380.06 d/s
Right Gluteus Maximus Strength	30.5%	21.9%
Left Gluteus Maximus Strength	30.6%	20.7%
Right Gluteus Medius Strength	30.5%	22.6%
Left Gluteus Medius Strength	30.2%	22.4%

d/s= degrees per second; %= strength expressed as a percentage of body weight

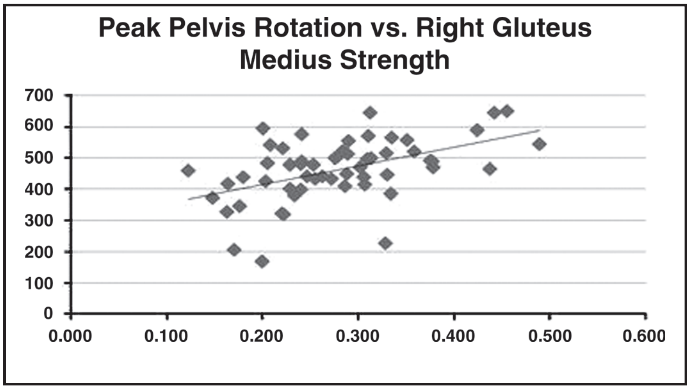

Figure 5. *Peak Pelvis Rotation Speed vs. Right Gluteus Medius Strength. Note: Strength is shown as a percent of body weight and rotation speed is measured in degrees/second.*

strength between high handicap and low handicap groups.

Correlation Data

A Pearson Product Moment Correlation was performed to see if there was a correlation between peak pelvis rotation speed and strength of the gluteus maximus and/or gluteus medius muscles (Figure 5). A fair correlation existed (r= .419-.490) between peak pelvis rotation and strength of the gluteals (Table 3). A fair correlation is considered to be between r= .25-.5.

DISCUSSION

The significant difference found in peak pelvis rotation speed between the high and low handicap groups was similar to that found by Cheetham et al indicating a significantly faster peak rotation speed in the low handicap group.[3] The average peak pelvis rotation speed of the low handicap group in the current study was 123.15 degrees/second faster than the high handicap In comparison, the two groups in Cheetham's study had an average difference of 82.00 degrees/second. A potential explanation for the increased range seen in the current study is that the authors included subjects with no golf experience while Cheetham did not.

The low handicap group (LHC) had significantly stronger gluteus medius and maximus muscles bilaterally. These results have many potential implications. Several authors have investigated the relationship between raw strength versus speed in other rotational sports. Pugh, Koveleski, Heitman, and Parsall compared the grip strength and arm strength of experienced and inexperienced softball players to their underhand pitching speed, and found a correlation between grip strength and throwing speed , p =/< .05.[12] Similarly, a fair correlation was found in the current study between gluteus strength and peak pelvis rotation speed.

Clearly, raw strength accounts for some of the difference in peak pelvis rotation speed. Other potential factors that may affect this variable include gender, the role of muscle fiber type, and motor learning. The majority of the low handicap group participated in sport specific training for golf in addition to playing an average of four days a week. This being the case, low handicap golfers could have experienced some muscle fiber type adaptations which might play a role in pelvis rotation speed. Gender, as a factor in pelvic rotation speed was not examined.

The role of motor learning in strength development was examined by Selvanayagam, Riek, and Carroll who proposed that the early neural responses to strength training might precede long-term neural adaptation, which ultimately will lead to increased strength.[13] The findings from the current study suggest that the LHC group could have more neural responses as compared to the high handicap group (HHC) which in turn would lead to increased motor recruitment both in terms of speed of recruitment and number of fibers stimulated. Ultimately this could lead to increased pelvis speed.

Table 3. *Correlation Data between Peak Pelvis Rotation Speed and Strength.*

Tested Muscle:	Pearson Product Moment Correlation*
Right Gluteus Maximus	r = 0.419
Left Gluteus Maximus	r = 0.430
Right Gluteus Medius	r = 0.490
Left Gluteus Medius	r = 0.466

*All correlations are statistically significant at the p<0.01 level.

Clinical Implications

Normalizing strength to body weight has the potential implication of carry over into clinical practice. By demonstrating that the LHC group had significantly more strength as a percentage of body weight as compared to the HHC group, it is proposed that gluteus strengthening should be incorporated into golf training and golf injury rehabilitation. A golf specific training program that includes repetition and movement in rotational patterns should be implemented in order to increase speed and efficiency of recruitment and establish motor learning which in turn will increase peak pelvis rotation speed and power during the golf swing. In addition, therapists should incorporate gluteus strengthening when treating injured golfers.

Limitations

A possible limiting factor in this study is true muscle isolation during manual muscle testing. Standardized protocols were used, but compensation could not be ruled out. A key compensatory muscle due to gluteus medius weakness is tensor fascia late recruitment. To strengthen the findings of this study an EMG analysis could have been utilized in order to determine recruitment of the gluteus medius and gluteus maximus and to rule out compensation of other musculature. Another limitation could be that the subjects were asked to wear unfamiliar equipment while performing the swing analysis. Even though five practice swings were given to allow the subject to become familiar with the electromagnetic sensor vest, normal swing mechanics could have been altered due to the equipment. A third limitation is the assumption of handicap for non-golfers. Most subjects recruited for this study had a USGA approved handicap, if subjects were new to golf or did not have enough experience to obtain a handicap, the assumption was made that the subject would have a handicap of 18 or higher.

CONCLUSION

Golfers with a low handicap are more likely to have increased peak pelvis rotation speed as well as increased gluteus maximus and medius strength when compared to high handicap golfers. The relationships between increased peak pelvis rotation and gluteus maximus and medius strength in low handicap golfers have implications in designing golf training and rehabilitation programs. Further research needs to be conducted in order to explore the nature of these implications.

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