Abstract

Context: Golf requires effective movement patterns to produce an effective swing and performance. **Objectives:** The study aimed to determine the relationship between the Titleist Performance Institute golf specific functional movement screening (GSFMS) composite and individual element scores and golf performance by assessing a player's handicap; clubhead speed; side accuracy; ball speed; peak pelvis rotation speed; swing sequence and common swing faults. **Design:** Cohort study, clinical measurement. **Setting:** English golf club. **Participants:** Eleven amateur golfers: 5 males (age: 37.2±18.7 years; height: 184.4±9.6cm; body mass: 89.5±13.4kg; handicap: 9±6.6) and 6 females (age: 53.7±15.0 years; height: 166.8±5.5cm; body mass: 67.9±16.6kg; handicap: 13±6.1). **Main outcome measures:** GSFMS composite and individual element scores and golf performance variables. **Results:** Significant relationships existed between GSFMS composite scores and handicap (*r*= -0.779, p=0.005); clubhead speed (*r*= 0.701, p=0.016); ball speed (*r*= 0.674, p=0.023); and peak pelvis rotation speed (*r*= 0.687, p=0.019). Significant relationships existed between 90°90° golf position and clubhead speed (*r*=0.716,p=0.013), ball speed (*r*=0.777,p=0.005), seated trunk rotation and peak pelvis rotation speed (*r*=0.606,p=0.048), single leg balance and handicap (*r*=-0.722,p=0.012), torso rotation and handicap (*r*=-0.637,p=0.039) and peak pelvis rotation speed (*r*=0.741,p=0.009). Single leg balance, overhead deep squat, and pelvic tilt were the GSFMS tests which participants had most difficulty in performing. The most common swing faults identified included loss of posture, slide, chicken winging and early hip extension. **Conclusions:** The GSFMS may be used to identify movement limitations that relate to golfing performance. These findings may potentially allow intervention to correct movement patterns and potentially improve golf performance.

Keywords: Clubhead speed, composite score, handicap, single leg balance, movement

Introduction

Golf is played by an estimated 55 to 80 million people worldwide in 208 countries; with over 4.1 million golfers registered in Europe, and over 660,000 registered in England in 2015.[1-4] Successful performance is determined by the player with the fewest shots during the round[5] and requires technical skills including the golf swing, chipping and putting.[5-7] The golf swing is a complex, dynamic, asymmetrical whole-body movement which requires a coordinated sequence of muscle activation to produce and efficiently transfer high amounts of explosive power with clubhead speeds often exceeding 160 km/hr.[8-12] Muscular strength, mobility, coordination, flexibility and stability are required[7,13] for efficient performance and to minimise injury risk.[5,7,14-16]

The use of musculoskeletal screening has been advocated to investigate injury and performance factors with one commonly used screen the Functional Movement Screen[17,18] which consists of seven movements namely the deep squat, in-line lunge, hurdle step, active straight leg raise, shoulder mobility, trunk stability push up and rotary stability scored from 0 to 3 producing a composite score of 21. Scores below 14 have been found to predict injury[19-23] and therefore appropriate interventions can be utilised to improve composite scores. In collegiate golfers, no significant correlation existed between composite and individual element Functional Movement Screen scores and performance variables while a one rep max squat demonstrated a significant correlation to performance.[24]

The use of activity specific screening has been identified as beneficial in determining movements that may relate to injury.[25] Within golf the Titleist Performance Institute golf specific functional movement screening (GSFMS) has been developed[26,27] which assesses a golfer's flexibility, strength and balance using 17 different tests in golf specific postures to identify physical limitations which may influence swing performance.[27] Only one previous study has investigated the relationship between the GSFMS and performance, Gulgin et al (2014)[27] utilised 12 different tests of strength, flexibility and balance to investigate the relationship between these movements and 14 different golf swing faults. Significant relationships existed between golf swing faults, toe touch and early hip extension, right side bridge and early hip extension and right side bridge and loss of posture. Golfers that could not perform an overhead deep squat correctly or single leg balance on left side were 2-3 times more likely to exhibit early hip extension, loss of posture, or slide during the golf swing in comparison to those who could correctly perform an overhead deep squat. It was suggested that common swing faults are linked to inconsistent ball striking and reduced performance[27] however, no other performance factors were investigated. In this study cervical rotation, forearm rotation, wrist extension, wrist flexion and wrist hinge were excluded from the GSFMS. However these movements are important within the golf swing as the hands maintain contact with the golf club throughout and enable the correct position at the top of the backswing and influence the rest of the swing.[28,29] Research has shown an increased wrist hinge is positively correlated to increased ball velocity.[28] Furthermore the study by Gulgin et al (2014)[27] limited the measurement of performance variables to golf swing faults and did not directly measure performance utilising variables such as a player's handicap, clubhead speed, side accuracy, ball speed, peak pelvis rotation speed and swing sequence which may potentially increase methodological rigor.

The aim of the current study was to investigate the relationship between the GSFMS composite and individual element scores and the golf performance measures of player's handicap, clubhead speed, side accuracy, ball speed, peak pelvis rotation speed, swing sequence and common swing faults in relation to implications for performance and injury.

Methodology

Study design

A correlational study design was used to determine the relationship between GSFMS composite and individual element scores and golf performance variables.

Participants

Eleven participants volunteered to participate in the study and their demographics are outlined in table 1. Participants were recruited from an English golf club and had an active handicap which required the submission of three or more qualifying cards for their handicap within the previous year.[30] The inclusion criteria specified a maximum active Congu handicap of 28 for men and 36 for women;[14,31] golf participation on a weekly basis in the year prior to the study; a minimum of five years golf experience and participants had to be aged between 18 and 70 years. Exclusion criteria included any injury within the previous six months[7] that prevented golf participation. Prior to the study commencing ethical approval was gained from the University Ethics Committee in accordance with the declaration of Helsinki**.**

Insert table 1 here

Procedures

Descriptive data collected from all participants, included age (years), height (cm), body mass (kg), current golf handicap, dominant side and the duration of golf participation. All GSFMS scores and performance data collection was performed by a graduate sport therapist trained in GSFMS and data collection using the K-vest and Trackman. Screening was performed at a golf studio and participants performed a standardised warm up[32] led by the researcher prior to testing consisting of arm circles, overhead extension, overhead side bends, golf rotations, modified side bends, partial squats and side lunges.

GSFMS

Participants were screened using the GSFMS which consists of 17 individual tests with a maximum composite score of 36 points (pts) achievable.[26] If the participant suffered pain or was unable to achieve the specific movement requirements they were awarded 0pt. The researcher demonstrated the movement and provided standardised instruction described by Rose (2013).[26] The screening was conducted in the same order described by Rose (2013)[26] with 30 seconds rest in between movements and participants performed each movement twice and the highest score was recorded. Prior to conducting testing an intra-rater reliability intraclass correlation coefficient ($ICC_{3,1}$)[33] was calculated by the researcher performing the GSFMS on seven injury free participants who were not part of the investigated population. Values of r=0.97 demonstrated excellent intra-rater reliability.[33]

Golf performance measurement

For all shots participants used their own five-iron and five warm-up shots were performed[34] followed by hitting four golf shots using their full swing from a golf mat to a standardised target 200 yards away during which swing, clubhead speed, (mph) side accuracy (meters), peak pelvis rotation speed (degrees per second), ball speed (mph) and swing sequence were recorded.[27,32] Side accuracy is the distance to the left or right of the predetermined target line that the ball has travelled in meters.[35] Accuracy and distance are two of the most important performance factors.[8] Clubhead speed is the speed of the clubhead at impact with the golf ball.[7] Ball speed is the speed of the golf ball immediately after impact.[7] Swing sequence is the order body parts move during the golf swing within this study it refers to the order of motion of the pelvis, trunk, arms and clubhead during the downswing.[32] Peak pelvis rotation speed is the maximum rotation speed the pelvis achieves during the downswing.[32]

Participants rested for 30 seconds between shots and received no feedback regarding their performance. Clubhead speed, side accuracy and ball speed were calculated using Trackman 3e (Vedbaek, Denmark) (figure 1) which is a portable wireless 3D golf launch monitor using single radar technology to record ball flight and impact data.[36,37] An Apple iPad Air 2 (Shenzhen, China) with trackman software loaded on it was used to enable the data to be transferred automatically after each swing.[37] The Trackman device was placed on the ground mounted upon its stand facing the target three meters behind the ball[38] and was calibrated on the iPad creating a straight line on the iPad screen which enabled the researcher to move the Trackman 3e device to ensure a straight line went through both the ball and the specified target 200 yards away.[38] The Trackman is recognised as a performance measure and is used by hundreds of tour professionals and coaches.[37,38] The researcher had used trackman as a performance monitor for two years and was trained in the use of the Trackman by a golf professional.

Insert figure 1 here

The participant's four swings were recorded down the line using an Apple iPhone 6s (Shenzhen, China) allowing the target line to be reviewed; the front view was recorded using another Apple iPhone 6s (Shenzhen, China)[27] and this view allowed the anterior view of the body and golf swing posture to be observed. Both phones were mounted on tripods (Manfrotto Compact, Cassola, Italy) four meters away from the ball at waist height relative to the participant who was performing the swings and recordings were uploaded via Trackman application software to allow analysis for any swing faults outlined in table 3. Trackman allowed the researcher to play the swings in slow motion, pause them and apply lines, boxes and angles.[27]. Thirteen swing faults were described as present or not present (table 2) which was determined by assessing if each individual swing fault was present in two or more of the four swings completed.

The participants peak pelvis rotation speed and swing sequence was recorded using a K-vest (Bentley Kinematics, Exton, Pennsylvania) (figure 1) which is a 3D motion analysis system used to monitor the golf swing. The K-vest utilises four wireless sensors, a receiver, hip, shoulder and lead arm garments, a phone with a video camera (iPhone 6s, Shenzhen, China) and a laptop with K-vest software (Bentley Kinematics, Exton, Pennsylvania). The four sensors where placed in four different locations important during the golf swing (figure 1).[32] One sensor was located on the central posterior aspect of the sacrum using the hip garment as illustrated in Callaway et al, 2012.[32] The hip garment was applied 1cm below the iliac crest. The shoulder garment was worn so that the sensor was located between the shoulder blades on spinous processes of T3-T5.[32] The lead arm sensor was placed on the arm closest to the target and located at the mid shaft of the humerus directly over the biceps brachii muscle by measuring from the head of the humerus to the medial epicondyle of the humerus belly of the biceps brachi muscle using a tape measure. The wrist sensor was attached to the players golf glove on their lead hand and a strap was placed around their wrist to keep it secure.

K-vest calibration was performed in accordance with the manufacturer guidelines which required the participants to stand with an erect posture square to the target holding their 5-iron longways with their elbows straight and their hands shoulder width apart above their knees. Four swings were completed, and peak pelvis rotation speed and the swing sequence were recorded via the K-vest software[32]. Reliability and validity tests have shown the K-vest is equivalent to the gold standard method of 3-dimentional video motion analysis.[32]

Insert table 2 here

Statistical analysis

Clubhead speed, handicap, peak pelvis rotation speed, side accuracy, GSFMS composite score and ball speed were reported as means and standard deviations and

95% confidence intervals. Descriptive statistics were used to report the frequency of individual test limitations within the GSFMS; swing faults and the association between the two. An unpaired t-test was performed to compare differences between male and female golfers for GSFMS composite score and clubhead speed, handicap, peak pelvis rotation speed, side accuracy and ball speed and a Shapiro-Wilk test and Levene's test of homogeneity of variance were used to determine normal distribution and homogeneity of variance. Pearson's correlation coefficient (*r*) was used to determine the relationship between GSFMS composite and individual element scores and clubhead speed, handicap, peak pelvis rotation speed, side accuracy and ball speed. Statistical analysis was performed using SPSS version 24.0 and statistical significance was set at $P<0.05$.

Results

Table 3 reports golf performance data for clubhead speed, ball speed, side accuracy, peak pelvis rotation speed and swing sequence. Data were normally distributed as determined by the Shapiro-Wilk test and Levene's test for equality of variances revealed homogeneity of variance. An unpaired t-test revealed no significant difference existed between handicap ($p=0.326$), side accuracy ($p=0.754$), peak pelvis rotation ($p=0.275$). Significant differences existed for clubhead speed ($p=0.004$) and ball speed ($p=0.002$). No significant difference existed for composite GSFMS score ($p=0.271$). Table 4 reports GSFMS individual element scores.

Insert table 3 here

Insert table 4 here

Table 5 reports the individual GSFMS components and the ability of participants to perform the movements. Participants had greatest difficulty performing bilateral single leg balance (100%), overhead deep squat (91%), and pelvic tilt (91%).

Insert table 5 here

Table 6 reports common swing faults; it highlights the most common swing faults that participants presented with were the loss of posture (91%), slide (73%) and chicken winging (55%).

Insert table 6 here

Table 7 reports the association between common swing faults and GSFMS limitations and the number of participants with these elements. It demonstrates that loss of posture and slide within the golf swing were the most frequently seen when the participants had limitations in single leg balance; overhead deep squat; pelvic tilt and the 90º/90º test in golf posture.

Insert table 7 here

A significant strong negative correlation existed between GSFMS composite score and golf handicap (r= -0.779, p=0.005) (figure 2) as demonstrated by values between 0.60 and 0.80.[39] The lowest handicap of 0 had the highest GSFMS composite score of 29.

Insert figure 2 here

A significant strong positive correlation existed between GSFMS composite score and clubhead speed (r= 0.701, p=0.016) (figure 3). The lowest clubhead speed recorded was associated with the lowest GSFMS composite score of 16.

Insert figure 3 here

A significant strong positive correlation existed between ball speed and GSFMS composite score (r= 0.674, p=0.023) (figure 4).

Insert figure 4 here

A significant strong positive correlation existed between peak pelvis rotation speed and GSFMS composite score (r= 0.687, p=0.019). The four lowest peak pelvis rotation speeds were also associated with the lowest GSFMS composite scores (figure 5).

Insert figure 5 here

Table 8 reports *r* values for GSFMS composite score and golf performance variables. Significant values existed for handicap, clubhead speed, ball speed and peak pelvis rotation speed. No significant relationship existed for side accuracy or swing sequence.

Insert table 8 here

Table 9 reports *r* values between individual GSFMS elements and golf performance variables. Significant findings existed for 90° 90° golf position and ball speed and clubhead speed, seated trunk rotation and peak pelvis rotation speed, single leg balance and handicap, torso rotation and handicap, torso rotation and peak pelvis rotation speed.

Insert table 9 here

Discussion

The aim of the current study was to investigate the relationship between the GSFMS composite and individual element score and golf performance measures and common swing faults in relation to implications for performance and injury. Significant findings existed between GSFMS composite score and handicap, ball speed, clubhead speed and peak pelvis rotation speed.

Handicap and GSFMS composite score

The significant strong negative correlation between the GSFMS composite score and handicap suggests that effective functional movement may relate to performance and agrees with previous findings that lower handicap golfers have greater physical capabilities (strength, flexibility and balance) than higher handicaps.[6,14,40,41] A lower handicap is associated with increased strength, flexibility and balance[40] and greater shoulder, hip and torso flexibility. For practitioners working with golfers this is significant as hip; pelvis and lower back strength is key for golf performance and the transferal of energy.[6,14]

Clubhead speed and GSFMS composite score

The significant strong positive correlation between clubhead speed and GSFMS composite score agrees with previous findings that have identified higher levels of power and strength assessed through functional tests including medicine ball throws, grip strength and countermovement jumps and a positive correlation to increases in clubhead speed.[42-44] Clubhead speed at impact is an important performance factor used in many studies as increases in clubhead speed are positively correlated to increases in driving distance.[43,45,46] However, driving distance is not always increased due to an increased clubhead speed as this depends on the quality of the strike between the ball and clubface and therefore ball speed was measured as it provides a more accurate measure for the distance the ball is hit.[7]

Ball speed and GSFMS composite score

The significant strong positive correlation between ball speed and GSFMS composite score suggests that efficient movement patterns as determined by the GSFMS can influence ball speed. Improvements in physical capabilities (power, flexibility, balance, core stability and strength) through golf specific strength and conditioning programs have resulted in increased clubhead speed.[16,44,47-49] Gordon et al (2009)[43] reported a significant correlation between clubhead speed and total body rotational power and chest strength and the rotational ability of the hips, spine and shoulders is related to increased performance using clubhead speed.[5]

Peak pelvis rotation speed and GSFMS composite score

The significant strong positive correlation identified between peak pelvis rotation speed and GSFMS composite score may encourage the implementation of exercises that could potentially increase pelvis rotation speed and include gluteal exercise programmes that combine strength and speed development. Lower handicaps are correlated to greater peak pelvis rotation speed and gluteus medius and maximus strength[32] which are actively recruited throughout the golf swing to maintain pelvic stability and a stable base to allow greater power generation. Pelvis rotation is important to produce efficient ball striking and enable maximum power transfer from the clubhead to the ball.[50] The downswing should begin with rotation and lateral slide of the pelvis due to the contraction of the knee and hip extensors of the trail leg.[8,46,51,52] This enables sequential acceleration of the trunk, shoulders, arms and then clubhead therefore increasing the power generated and control through the swing enabling higher speeds and greater accuracy to be produced.[52,53]

Side accuracy and GSFMS composite score

No relationship was identified between side accuracy and GSFMS composite score despite the importance of accuracy in golf. Lower handicap golfers have greater physiological characteristics therefore allowing the correct positions to be obtained during the golf swing.[6,8,14,41] In the current study, participants only hit four golf shots, whereas a round of golf requires approximately 30 to 40 full golf swings depending on a player's ability and the influence of accuracy may become more significant if a greater number of swings are performed when fatigue and physiological restrictions are more likely to occur.[12] Therefore it is possible that fatigue effects may influence side accuracy and were unlikely to be a factor in this study.

Swing sequence and GSFMS composite score

No significant relationship was identified between swing sequence and GSFMS composite score despite previous research identifying that limitations in one movement may cause limitations throughout the swing.[32] Two main swings exist within golf; the modern and the classic golf swing, however all golfers have their own unique swings styles.[54] The modern golf swing limits lumbopelvic rotation in the backswing and produces greater rotation of the torso with a hyperextended lumbar spine during the follow through.[9] The classic golf swing produces equal amounts of shoulder and lumbopelvic rotation and maintains a neutral spine position during the follow through.[9] The modern golf swing is the most frequently seen today and has been linked to increased clubhead speed, ball speed and distance due to the restriction in pelvic turn which increases the angular displacement between the pelvis and shoulders creating stored energy. [8,28,46,55] Prior to the downswing pelvic rotation commences further increasing the stretch and muscle elastic recoil effect; this creates additional rotational velocity and transferral of power at impact in an efficient golf swing.[8,46,55] However, the modern swing is considered to place greater torsional load on the body, especially the lumbar spine; with lower back injuries highly prevalent among both amateur and professional golfers.[54,56,-59] Therefore there is a need to balance potential performance benefits against injury risk.

GSFMS element score and golf performance variables

The finding of a negative correlation between torso rotation and handicap and a positive correlation with peak pelvis rotation speed reflects thoracic spine movement. Greater stability when performing a backswing enhances the base of support allowing more power to be developed and greater peak pelvis rotation. A negative correlation between single leg balance and handicap may relate to the importance of balance during the golf swing to to enable effective weight transfer to create power and produce a consistent repeatable swing. Reduced single leg balance is associated with swing faults[27] and reduced accuracy and consistency and ultimately higher handicaps.

Seated trunk rotation was identified as being positively correlated to peak pelvis rotation speed. Limited torso rotation may contribute to swing faults including reverse spine angle as the rest of the body compensates for reduced thoracic spine mobility. This may prevent the adoption of an optimal position to commence the downswing and therefore hip speed may reduce and compensation may occur through the kinetic chain resulting in injury. The finding of a positive relationship between 90° 90° golf position and ball speed and clubhead speed may represent the efficient adoption of external rotation of the shoulder which allows the backswing to be performed without excessive arching of the upper thoracic region which can potentially reduce power and ball/clubhead speed.

Common physiological restrictions in the GSFMS

The most frequent physical restrictions in the GSFMS tests were single leg balance, overhead deep squat and pelvic tilt which may provide areas for intervention. Previous research has identified the single leg balance and overhead deep squat as the most restricted movements.[27] The overhead deep squat assesses bilateral mobility of the hips, knees, ankles, shoulder, spine and core stability. It was reported that 67% of golfers who could not perform a deep squat had early hip extension, 54% had loss of posture and 29% had a slide.[27] The current study found that 90% had loss of posture, 60% had early hip extension and 80% had slide. The overhead deep squat is an important movement to assess for golf performance due the requirement for golfers to adapt a squat like position to create a stable base to rotate around enabling power creation and stability throughout the swing.[5] Participants who were unable to perform the deep squat most commonly presented with loss of posture; this means the golfer has changed knee flexion angle, trunk flexion angle or head position between their address posture and impact position.[27] Movement compensations throughout the golf swing can impact on swing plane, timing, balance and rhythm causing golfers to rely on last minute hand compensations to square the clubface at impact and hit the ball straight resulting in inconsistent performance.[27] Consequently, improving deep overhead squat may improve posture within the golf swing.

The single leg balance test assesses static balance and proprioception of the lower limbs in addition to core stability.[18] Studies have shown single leg balance is greater in lower handicap golfers.[14] A previous study reported that participants who could not perform single leg balance on their lead side had a three times greater risk of early hip extension, slide and loss of posture during the downswing.[27] Weight is transferred to the trail side during the backswing and the lead side during the downswing, therefore the ability to maintain balance during this movement prevents swing adaptations.[7,27] The current study found that participants who were unable to perform the single leg balance test; 91% demonstrated loss of posture and 73% slide. Slide indicates increased lateral hip movement during the downswing towards the target rather than rotation resulting in the club to feel trapped behind the body. This results in reduced power and speed generated from the upper body[27] and potentially shot accuracy and therefore, improving single leg balance may prevent a slide swing fault occurring. Golf requires dynamic balance as weight is transferred during the golf swing to develop power with weight finishing primarily on the lead leg and requires integration of the kinetic chain whilst maintaining balance.[14] The GSFMS tests static balance which is not a specific requirement of golf[60] and requires the participant to close both eyes which would not occur during golf. Furthermore, the test is performed on a flat surface whereas golf requires numerous uneven stances; including uphill; downhill and stances requiring one foot in a bunker and one foot outside the bunker.[7,14] The single leg bridge may also provide an area for intervention as it has been reported to correlate with slide as gluteal strength provides pelvic stability helping to prevent lateral side.[27]

The pelvic tilt test assesses the ability to control the position of the pelvis and mobility of the lumbar spine and hips.[61] The current study found of the participants presenting with pelvic tilt; 90% had loss of posture; 50% had early hip extension and 70% had slide. and 50% had chicken winging. Early hip extension is where the hips move closer to the ball during the downswing causing a restriction in pelvis rotation. This alters posture and causes the hands to become trapped behind the body due to the reduced space.[27] Lower handicap golfers have greater hip and torso flexibility and strength which is required to maintain a stable base to rotate around and transfer energy.[6,14] The golf swing requires a neutral spine angle throughout to reduce the pressure on the lumbar spine especially during the repetitive rotation required. Future research may wish to investigate the impact of spine angle especially due to the high level of lower back injuries sustained during golf.[62]

Chicken winging was the third most common golf swing fault reported within the current study and is where the lead arm flexes through impact reducing the width and subsequently clubhead speed generated. Chicken winging occurred when numerous GSFMS tests were restricted; 90º/90º golf posture (56%); pelvic tilt (50%); overhead squat (60%) and single leg balance (55%). This suggests that lower body restrictions lead to compensations within the kinetic chain impacting the upper body during the golf swing. The kinematic swing sequence is important during the golf swing to develop movement efficiency, momentum and enhance golf performance.[8,63,64] Sequential acceleration within the golf swing creates a smooth acceleration.[65] Whereas incorrect downswing sequence which is frequently seen in amateur golfers can lead to jerk which is a change in acceleration[65] and the associated inefficient power transfer potentially increase the injury risk especially at impact.[12,65]

The optimal kinematic swing sequence for efficient energy transfer and power generation involves the legs producing ground reaction forces which then transfers energy to the pelvis, trunk, arms and then the clubhead.[32,46,63,64] This coordinated sequence involves the kinetic chain as movement of one joint affects the movement of another. If one movement within the kinetic chain is dysfunctional the whole golf swing is affected potentially leading to injuries and reduced performance through reduced ball and clubhead speed.[32,46,63,66,67] Therefore, the correct kinematic sequence is important to prevent compensation and increased stress on other areas of the body which can lead to overuse injuries.[68] Poor swing mechanics have been related to an increased injury risk due to the repetitive, forceful, asymmetrical nature of the sport with over 45% of golf-related lower back injuries due to poor swing mechanics.[11-13,56,62,69] Therefore, potential improvement in swing mechanics could lead to reduced injury risk[56,70] especially in amateurs who often suffer injuries due to poor swing mechanics with these occurring more in mid to high handicap players (above 9 handicap).[56,59,70] Swing sequence depends on the effective engagement and sequencing of muscles to transfer power and appropriate range of motion to perform the desired movement.[71]

Limitations and future research

Potential limitations within the study included that participants used their own five-iron which resulted in participants using five-irons made by different equipment manufacturers which may potentially influence clubhead speed.[27,72] However, this improves the ecological validity of the study as golfers frequently play specific clubs and it therefore provides a greater replication of the sport.[73] The small sample size presents a limited representation of the golfing population and the majority of the GSFMS have a mobility element (15/17) and a greater consideration of strength is required as only the bridge with leg extension measures this component and no specific power test is included. Furthermore, there is no test specific to golf which assesses the ability of the body to perform numerous rotational, weightbearing and high-speed movements together. Therefore, future research could look to develop tests which assess the kinetic chain movements a golfer requires.

Conclusion

This study was the first to investigate the relationship between GSFMS composite and individual element scores and golf performance. The study demonstrated that GSFMS composite scores were correlated with lower handicaps, greater ball speed, clubhead speed and peak pelvis rotation speed which have been linked to increased golf performance.[8] The GSFMS could potentially be used as an assessment tool to aid the development of strength and conditioning programs which could aid the correction of movement deficiencies and potentially improve golf performance by developing certain physiological characteristics. Golf specific training programs focusing on power, strength and flexibility performed by amateur golfers have demonstrated an increase in clubhead speed and driving distance.[6,44,48,49] Physical conditioning aids muscle recruitment to allow the correct sequencing for optimal performance.[46]

GSFMS individual element scores identified the 90° 90°golf position, seated trunk rotation, single leg balance and torso rotation as important elements to consider. The most common GSFMS restrictions were single leg balance, overhead deep squat and pelvic tilt. The most common swing faults golfers presented with included loss of posture, slide, chicken winging and early hip extension. Golfers most commonly presenting with slide and loss of posture displayed the most prevalent restrictions in single leg balance, overhead squat, 90º/90º test in golf posture and pelvic tilt. Therefore, emphasis could be placed on assessing these movements if limited time was available to improve swing mechanics, increase performance and potentially reduce injury risk.

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