The Golf Movement Screen (GMS) is related to spine control and x-factor of the golf swing in low handicap golfers.

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ABSTRACT

The aim of the study was to investigate the association between the golf movement screen (GMS), x-factor, which is the separation between the upper torso and pelvis rotation, and biomechanical movements of the pelvis, thorax and spine during the back swing and impact of a golf shot in low handicap golfers. In total, sixty-two golfers were involved in this study (n = 40 male, n = 22 female); the mean age of the sample was 15.4 ± 2.4 years. For the GMS, all participants were assessed on their movement ability over a total of 10 different exercises. Following a thorough warm-up routine of practice swings, each golfer then performed a single trial for biomechanical analysis. Biomechanical data was collected using an electromagnetic tracking system. Four of the 10 exercises had a significant correlation with x-factor (r = 0.25 - 0.33; $p < 0.05$). Four exercises had moderate correlations with spine rotation at the top of back swing. Spine side bend had a significant correlation with nine of the 10 exercises and total GMS score (r = 0.26-0.53, $p < 0.05$). Movements of the pelvis and thorax at the top of back swing had minimal associations with the GMS. At impact, trunk inclination, thoracic rotation and squat had small to moderate significant relationships with biomechanical movements ($p < 0.05$). Movement competency, as measured by the GMS, is associated with important aspects of swing mechanics. In particular, golfers who achieve better scores in the GMS have better spine control and can create a greater x-factor during the golf swing.

Key words

Golf, low handicap, functional movement, biomechanics, strength and conditioning

INTRODUCTION

Movement screens are developed to test an individual's movement competency over a set of exercises that have a specific criterion (14,31,37). Previous research that has been conducted between movement screens and golf have included the functional movement screen (FMS) (42) and the Titleist performance institute screen (TPI) (27). Additionally, numerous studies have examined the relationship between the functional movement screen (FMS) and sports performance (8,11,22,41,42). A number of studies have identified limited associations between movement competency and athletic performance (29,41,42). However, it has been identified that movements in the FMS are positively associated with upper body power and agility in healthy men and women (41). Soldiers that achieved a higher total score on the FMS were found to have enhanced balance, better hamstring flexibility and more efficient lower extremity function (46). Track athletes who have no asymmetrical differences, indicated by the FMS, had improved performance compared to athletes with one or more asymmetries (8). Currently, only one study has examined the association between the FMS and golf swing speed (42), conversely it was found that physical performance tests were better predictors of club head velocity compared to FMS scores (42). However, it could be argued that the FMS was not specifically designed to predict golf performance, therefore, a screen that examines the movement demands specific to golf is needed, and that movement competency is more closely associated with golf mechanics rather than gross measures of golf performance.

The Titleist Performance Institute screen (TPI) is a movement screen that has been developed specifically to assess a golfer's movement. The rationale behind the screen is to simulate the movement demands golfers experience during a golf swing in order to be technically competent. Currently, only one study has investigated the relationship between TPI exercises and technical swing performance (27). Three out of 13 exercises in the screen (overhead squat, bridging and single leg balance), were related to movement deficits during the golf swing (27). The mean age was 25.4 years and handicap of the group was 14 indicating that the participants were lower level golfers; therefore, technical deficiencies in the golf swing might be caused by playing ability and not physical limitations. This means ten of the movements in the TPI screen showed no relationship with swing mechanics. Additionally, the rating system adopted in the TPI screen appears to be broad and vague by rating movements as a whole and giving a screening handicap. Therefore, a need to investigate the relationship between body mechanics in a golf shot and movement function in young, low handicap golfers is pertinent to eradicate both swing and movement dysfunction from an early age.

Investigations of the biomechanics of the golf swing have typically examined the thorax, spine and pelvis (3,4,6,10,39,40). Research has also focused on the relationships between individual body segments, x-factor and swing velocity. X-factor is the separation between the upper torso and pelvis rotation, which is specifically defined as the difference in axial rotation between the thorax and pelvis at the top of the backswing (38), or where maximal separation occurs (39). Research has demonstrated that maximum x-factor and maximum upper torso rotation are highly related to club head speed in professional golfers (39). Additionally, torso-pelvis separation contributes to greater thorax rotation velocity and torso-pelvis separation velocity during the downswing, ultimately contributing to greater ball velocity (10,40). Peak pelvis rotation has also been significantly correlated to lower handicaps (6). Consequently, it is clear that spine rotation, thorax rotation and pelvis rotation all play an important role in the golf swing.

Therefore, as only 3 exercises in the TPI screen has been associated with faulty swing mechanics it seems pertinent to examine whether a new golf-specific movement screen is associated with control of the pelvis, thorax and spine during the golf swing. The purpose of the newly developed screen is to examine golfers on their ability to perform exercises that are relevant to strength and conditioning programs for golfers and body movements that are performed when swinging a golf club. Additionally, the rating system is more sophisticated than the TPI as it independently rates relevant body segments in each movement. Therefore, the screen could be used to specifically direct training and coaching interventions. However, it is unknown if the exercises in the GMS are related to golf swing mechanics. Consequently, the aim of the study is to examine the validity of the GMS by investigating the associations between competency in the GMS and biomechanical movements during a golf shot in low handicap young golfers.

METHOD

Experimental Approach to the Problem

In order to address the aims of this research a correlation study was conducted to determine the strength of relationships between the golf movement screen (GMS), and the biomechanics of the spine, thorax and pelvis during the back swing and impact of a golf shot. Low handicap golfers completed the GMS, followed by a standard golf shot using a 6-iron during which an electromagnetic tracking system was used to model the kinematics of the golf swing. Biomechanical analysis highlighted the range and direction of motion that occurred at the spine, thorax and pelvis during the back swing and impact, as well as allowing calculation of the x-factor. All testing took place towards the end of a competition phase of the season.

Participants

In total, sixty-two low handicap golfers from a National Development Pathway were involved in this study (n = 40 male, n = 22 female). Participants' mean age was 15.4 ± 2.4, ranging from 11-26 years, height 169.8cm (± 10.3), weight 61.9kg (± 9.6) and handicap 4 (ranging between +4 - 15). All participants were deemed talented because they had been selected on behalf of the national organisation as the best players for their age groups in the country, and the sample included both junior and adult golfers. Participant consent or assent (for those under 18, parental consent) and physical activity readiness questionnaires were collected prior to the commencement of testing. Ethical approval was granted by the institutional ethics committee in accordance with the declaration of Helsinki.

Golf Movement Screen (GMS)

The Golf Movement Screen is test battery that has been designed specifically to examine the movement competency of golfers, as described elsewhere (25). The GMS includes 10 exercises **(Supplementary file)**: trunk inclination, seated hamstring, seated thoracic rotation, rotation over fixed foot, lunge, overhead squat, basic balance, mini squat, diamonds and side plank. Each exercise is rated across a variety of the most important body segments that contribute to the movement. The body segments are rated and scored with a pass or fail, 1 for a pass and 0 for a fail, which accumulate to give a total score for each exercise. All exercise scores are then totaled to provide an overall GMS score. The GMS can be reliably used by experienced and novice raters (25). Specifically, total GMS score has excellent inter- and intra-rater reliability (overall GMS score ICC= 0.94 for inter and intra). Total exercise score has shown to have excellent intra-rater reliability in all 10 exercises, and excellent reliability in nine of the ten exercises from an inter-rater perspective (ICC= >0.75) (25). The GMS data was recorded, assessed and scored using an electronic tablet (IPad mini, Apple, USA). Most of the participants were familiar with the GMS, as they had completed this procedure on previous occasions. However, a correct demonstration of each GMS exercise was performed and a verbal description was included to clarify participant understanding.

Biomechanical data

Biomechanical data was collected using the Polhemus Liberty electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA), which is a motion capture system currently utilized by the national governing body (NGB) and professional golfers. Data was collected at a sampling frequency of 240 Hz. A transmitter, which contains three orthogonal coils (solenoids), generates three different electromagnetic fields in the region of 1–4000x$^{10-9}$ T. Magnetic flux generates proportional currents used to calculate a vector signifying the direction and strength of the magnetic field at the site of the sensor. According to the manufacturer, the static accuracy is 0.076 mm RMS for sensor position and 0.15° RMS for sensor orientation. The data is gathered via a transmitter from which information was attainted from sensors that were placed on the golfer. The transmitter was placed 1 m behind each participant during a golf shot.

Each participant wore a velcro body harness that caused little to no resistance to the golfer. The harness is used to attach sensors to the participant on selected body landmarks: centre of forehead, third thoracic vertebrae, lumbo-sacral joint. A static calibration using a 15 cm pointer pen was used to identify thorax and pelvis. To identify anatomical locations of the thorax, calibrations were made on the left and right acromio-clavicular joints, on the mid-axillary of the right-hand side of the thorax just below the armpit and low on mid-axillary on the midline of the rib cage. To identify anatomical locations of the thorax of the pelvis, calibrations were made at the right greater trochanter, left greater trochanter and superior point (mid coronal plane) of the left iliac crest (Mark Bull Golf Limited T/A Bull 3D, Somerset, UK). Spine rotation, spine bend and spine side bend were calculated using the joint coordinate system (JCS), which is measuring between the two adjacent segments to the joint (26). The head, thorax and pelvis are digitised during the calibration. This allowed the sensors to be located within the magnetic field created by the transmitter, which results in the construction of anatomical segment axes. The body segments examined in the current study were the pelvis, thorax and spine. X-factor is the separation angle created between the pelvis and thorax (McLean & Andrisani, 1997). The software measures x-factor during a golf shot, which is the maximum distance created between the pelvis and thorax. The software calculates the amount of movement within each segment relative to the neutral position (value of zero). For each segment three directions of movement are considered. The direction of movement is referred to in relation to the target. The target is defined as the end point at which the golfer is aiming to hit the ball. The outcome variables are listed in table 1.

Table 1. An overview of the segments analysis with description and direction of movement that occurred

Variable	Description	Positive	Negative
Pelvic sway	The amount the pelvis moves laterally during the golf shot.	Towards	Away
Pelvic thrust	The amount the pelvis moves backwards or forwards (flexion or extension) in the sagittal plane during the golf shot.	Forwards	Backwards
Pelvic Lift-	The amount of superior and inferior movements of the pelvis during the golf shot.	Superior	Inferior
Thorax sway	The amount the thorax moves laterally during the golf shot.	Towards	Away
Thorax thrust	The amount the thorax moves forward or backwards from the ball during the golf shot.	Forwards	Backwards
Thorax lift-	The amount of superior and inferior movement of the thorax during the golf shot.	Superior	Inferior
Spine rotation	The spine rotation curve is the difference between how much the pelvis and ribcage are rotating.	Towards	Away
Spine bend	The difference between forward bend of the pelvis and ribcage.	Flexion	Extension
Spine Side bend	The difference between side bend of the pelvis and ribcage	Towards	Away

The pelvis and thorax are measure in inches the spine movements were measured in degrees

Towards the target, away from the target, forwards to the golf ball, backwards from the golf ball, superior upwards, inferior downwards

Statistical analysis

GMS variables were correlated against the three-dimensional biomechanical variables. Data were examined for normality using a Shapiro-Wilk tests. Pearson's and Spearman's correlation coefficients were used, where data were, and were not, normally distributed respectively. The correlations were generated against all biomechanical measures of the pelvis, thorax and spine at three separate points during the golf shot; top of the back swing and impact. For x-factor a stepwise multiple regression analysis was also employed to determine which of the GMS exercises provide a cumulative ability to predict performance. The level of significance for all tests was set at an alpha level of $p < 0.05$ (12). Correlations were interpreted as trivial (r = 0.0-0.09), small (r = 0.10-0.29), moderate (r = 0.30-0.49), large (r = 0.50-0.69), very large (r = 0.70-0.89) and nearly perfect (r = >0.90) (28). All data were analyzed through SPSS (V.20 IBM, SPSS, Statistics).

RESULTS

Spine biomechanics during the golf swing showed a number of significant relationships with the GMS, both at impact, but particularly at the top of backswing (Table 2). As shown in table 2, all GMS movements were significantly correlated with at least one measure of spine control either at the top of backswing or at impact. Total GMS score and all but one of the individual movements were significantly related to spine side bend at the top of backswing, with total GMS score and the lunge demonstrating large correlations (r > 0.50, p < 0.01). Furthermore, moderate correlations were found between spine rotation at the top of back swing and total GMS (r = 0.33) score, and four GMS exercises (trunk inclination r = 0.36, thoracic rotation r = 0.30; squat r = 0.32; basic balance r = 0.31). Also, basic balance was significantly correlated with five out of six measures of spine biomechanics during the golf swing. Within the backswing the pelvis and thorax showed limited association with the GMS. Exceptions were basic balance (r = 0.30, p < 0.05) and mini squat (r = 0.25, p = 0.05) with thorax thrust and sway respectively. Pelvic sway at the top of backswing was significantly related to rotation over fixed foot (r = 0.37), diamonds (r = 0.31) and side plank (r = 0.27), and pelvic lift to the seated hamstring test (r = 0.32) and basic balance (r = 0.41).

At impact there were few significant relationships between the GMS and thorax and pelvis biomechanics during the golf swing. Exceptions were small to moderate significant relationships ($p < 0.05$) between trunk inclination and thorax sway (r = 0.51) and pelvic sway with trunk inclination (r = 0.42), thoracic rotation (r = 0.25) and squat (r = 0.27). Lastly, table 1 shows four exercises demonstrated significant, small to moderate relationships with x-factor; side plank (r = 0.33; $p < 0.05$), trunk inclination (r = 0.30; $p < 0.05$) and both squat and basic balance (r = 0.25; $p < 0.05$). The multiple regression analysis showed that the strength of the relationship increased to r = 0.49 when plank, trunk inclination and lunge were combined in a predictive equation.

Table 2. Correlation between spine movements at the top of back swing, impact and x-factor

Exercise	Top of Backswing			Impact			
	Spine Rotation	Spine Bend	Spine Side Bend	Spine Rotation	Spine Bend	Spine Side Bend	X-factor
Total score	-0.33**	-0.15	0.53**	-0.30*	0.24	-0.16	0.15
Trunk inclination	-0.36**	-0.17	0.14	-0.16	0.09	0.03	0.30*
Seated hamstring	-0.20	-0.26*	0.30*	-0.13	0.10	-0.26*	-0.02
Seated thoracic rotation	-0.30*	-0.03	0.33**	-0.15	0.21	-0.27*	0.13
Rotation over fixed foot	-0.17	0.00	0.49**	-0.10	0.02	0.10	0.16
Lunge	-0.16	-0.02	0.51**	-0.22	0.25	-0.10	-0.06
Squat	-0.32*	-0.04	0.29*	-0.24	0.23	-0.06	0.25*
Basic balance	-0.31*	-0.41**	0.35**	-0.48**	0.28*	-0.18	0.25*
Mini squat	-0.16	-0.12	0.30*	-0.14	-0.2	0.03	0.08
Diamonds	-0.04	0.03	0.37**	-0.07	-0.08	0.11	-0.07
Side plank	-0.18	0.12	0.34**	-0.23	0.2	0.32*	0.32*

*Sig. Relationship ($p < 0.05$)

** Sig. Relationship ($p < 0.01$)

DISCUSSION

The aim of the study was to examine the relationships between the golf movement screen (GMS), x-factor and the biomechanics of the spine, thorax and pelvis during the golf swing. The main findings were that x-factor had significant, small to moderate correlations with trunk inclination, basic balance, squat and the side plank. In total 24 significant correlations ranging from small to large were found between the GMS and biomechanical movements at the top of a back swing. The most significant correlations were observed between total exercise GMS scores and spine side bend and spine rotation at the top of back swing. A total of 10 significant correlations were found between GMS exercises and biomechanics at impact. Findings indicate that competency in the GMS is related to x-factor and spine control at the top of the backswing and at impact in low handicap golfers. Although explaining a small amount of variance, balance may be a particularly important screening exercise as it demonstrated significant relationships with most measures of swing mechanics.

The first major finding of the study was the association between x-factor and four exercises in the GMS. X-factor has previously been associated with higher swing speeds (5), greater ball velocity (10,40) and lower handicaps (6). Participants within the current study that had better trunk control, lower body balance, squat movement and oblique stability were more able to create a larger x-factor during the golf shot. Given that trunk inclination was moderately correlated with x-factor, it is suggested that athletes who can perform adequate movements in the trunk inclination test should also be able to create larger ranges of x-factor in the golf swing. Consequently, trunk control should be viewed as a key characteristic needed for golfers, and the trunk inclination should be deemed a key screening exercise to be used when testing golfers. If a golfer is out of balance during a golf shot it is likely their ability to rotate correctly around a stable pelvis could be negatively affected. Therefore, golfers that performed better on the basic balance test also created larger ranges of x-factor. Given that squat competency was shown to be related to x-factor in this study and that previous research has shown that squat performance in the FMS has been associated with reactive strength in youth football player (35) and squat performance has known to be related to lower body strength and power (1,7,17,18,20,21,24). Additionally, previous research demonstrates that measures of lower body power are strongly related to CHS, but with considerable variance left unexplained (e.g. (45). While the variance in the GMS is typically lower this may be important in accumulating training gains. Consequently, in the present study movement mechanics may help to explain some of the additional variance in golf performance. Therefore, it is proposed that a squat is a fundamental exercise to incorporate in strength and conditioning programs and screening assessments for golfers. Lastly, the side plank had a small correlation with x-factor. The side plank within the GMS is a measure of trunk stability, which involves oblique activation (19). The oblique muscles have been shown to activate between 42-64% of maximal levels during the acceleration phase of a golf swing (43). Additionally, trunk control might help to synchronize muscle activation as the trunk travels through a golf swing (43), creating higher levels of x-factor. Therefore, highlighting the potential impact trunk control, balance and core stability may have on x-factor; it is critical that screening protocols for golfers test these qualities.

The number of significant correlations found within spine movements at the top of the backswing suggests that all exercises within the GMS are associated with spine control. The requirement of the GMS is to maintain posture throughout each exercise. In order to achieve this an adequate amount of trunk and spine control is needed (19). Specifically, during a golf shot, stabilisation of the trunk requires activation of the erector spinae, quadratus lumborum, and rectus abdominis (2,33,34). It has been found that the erector spinae and obliques are highly active within a golf shot (43). The data presented in this study indicates that the participants who scored highly on the GMS showed a higher range of movement on the spine side-bend at the top of the back swing. It has been established that lateral tilting and forward movement of the trunk during the downswing were correlated with ball velocity (10). Therefore, a large lateral movement in the backswing may be a strategy adopted to create a position from which a golfer can generate higher swing speeds.

The majority of exercises within the GMS were significantly correlated with spine side bend at the top of back swing; with the lunge being the exercise with the strongest correlation. The lunge is a lower body exercise that has been considered to be fundamental in sport-specific conditioning (9) and is a whole-body movement that assesses muscle activation and control (14). It is suggested that a lunge performed correctly will highlight if an individual has control of the pelvis and lower legs (32). For example, it has been identified that the gluteus maximus, biceps femoris, and gastrocnemius–soleus complex are activated to maintain stability of the stance limb during ambulation of the lunge (30). Therefore, hip stability may create a base for the spine to rotate around, resulting in a larger amount of side bend occurring.

Previous research has found that the lunge is correlated to strength and power (16) and associated with measures of strength, reactive strength (35), agility (15), and balance and flexibility (13). Lower body power has previously been associated with club head speed in golf (45). Pelvic rotation impacts on power generated in the golf swing (6), which has been linked to lower handicaps (23). The gluteus maximus are activated in order to stabilize the lunge (30), and the gluteus maximus plays a substantial role in generating power in the golf swing (6). Findings from the current study infer that it would be worthwhile to screen the lunge and to use results to inform strength and conditioning prescription in golfers, as improved lunge ability may confer benefits for swing mechanics and golf performance.

At the top of the backswing there were also a number of significant small to large correlations with GMS exercises and spine rotation. Unsurprisingly, spine rotation has been associated with golf drive performance (40). As previously highlighted, the philosophy of the

GMS is to maintain posture as the exercises are conducted, which requires adequate levels of spine control (19). This is the first study to demonstrate that movement proficiency in the trunk inclination, thoracic rotation, squat and basic balance test are all related to spine rotation during a golf swing. Consequently, the ability to have good balance (basic balance), control the lower body (squat) and trunk (trunk inclination), and control large ranges of movement (thoracic rotation) will facilitate spine rotation during the backswing.

Compared to the spine, the thorax and pelvis during the backswing showed fewer significant relationships with the GMS. Nevertheless, at the top of backswing the basic balance and mini squat showed small correlations with thorax thrust and sway. Pelvic sway at the top of backswing had small to moderate correlations with rotation over fixed foot, diamonds and side plank, and pelvic lift to the seated hamstring test and basic balance. Although there are a number of exercises that associate with pelvic or thorax movements, the basic balance test had the most significant correlations compared with other exercises within the screen. Although the relationships are small to moderate, it seems prudent for golfers improve their balance to help with specific swing characteristics. Therefore, the basic balance test can be used to predict thorax sway and thrust, pelvis sway and as shown previously spine movements at the top of the back swing.

There were relatively few significant relationships between impact position and the GMS. Six of the significant correlations were with measures of the spine, reinforcing the link between the GMS and spine control. The trunk inclination test revealed moderate correlations with both variables that involve lateral movements of the hips and thorax (thorax sway and pelvic sway). Previous research found that low handicap golfers produce higher levels of peak lateral force from the top of the backswing to the impact position (44), resulting in greater weight transfer during this phase of the golf swing. Similarly, in the current study, a large and significant correlation was shown between thorax sway and trunk inclination. Additionally, previous research measured the strength of trunk rotation in both non-aiming (back swing) and aiming side (follow through) in professional golfers was measured (3). It was found that peak torque and total work on the golfers aiming sides were significantly higher than on their non-aiming side at all angular velocities. Therefore, trunk inclination is a measure of trunk control, golfers may use trunk control to create more thorax sway during the impact position, which may help a golfer create higher peak torque during the golf shot.

When examining the validity of the Resistance Skills Training Battery in adolescents, it was concluded that a relationship of r = 0.40 between movement competency and muscle fitness indicated acceptable construct validity (36). Findings from the current study demonstrate a number of similar strength relationships between golf movement competency and golf mechanics in young golfers, suggesting the GMS has acceptable construct validity. It is unlikely a movement screen will describe the majority of variance in an athletic skill, with physical fitness qualities likely to dominate. In golf, upper body strength and power are known to explain a large portion of the variance in club head speed during a golf shot(45). Future research should determine the overall contribution of competency in the GMS to predicting swing mechanics and golf performance when combined with additional measures such as strength and power. Nevertheless, the findings of the present research demonstrate that performance in the GMS can explain an important amount of the variance in swing mechanics.

PRACTICAL APPLICATIONS

As a result of the current study, it can be suggested that individuals who score better on the GMS may have greater x-factor and spine control during a golf shot. Golf is a sport of fine margins especially in high level golfers, therefore, if golfers or strength and conditioning coaches want to make small gains in performance, mastering exercises in the GMS would be a useful strategy to employ. Specifically, if individual scored low on the screen, strength and conditioning interventions should aim to improve postural control, mobility and stability, as these are key attributes that are tested within the GMS protocol. Findings from the current study indicate that competency in a variety of movements may be advantageous to the golf swing. In particular balance seems to provide the most consistent quality that is related with the backswing, impact and x-factor. Consequently, strength and conditioning coaches should attempt to incorporate exercises within the training programme that aim to develop trunk control, balance, technique when squatting and core stability in order to positively influence x-factor, which is essential for effective golf drive performance. Lastly, strength and conditioning interventions that target both power and movement competency may provide the greatest translation to golf performance, but research is needed to confirm this.

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