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The Association Between Stability and Swing Kinematics of Skilled High School Golfers

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ABSTRACT

The aim of this study was to investigate the possible relation between common stability tests and the linear and angular kinematics of the pelvis and upper torso. The stability and swing kinematics of 18 skilled high school golfers (mean hcp=-1.9) were measured. Scores obtained from the stability tests were related to both linear and angular kinematics. A decrease in stability in the prone bridge test and one-legged squat was associated with upper body sway away from target during the backswing. Furthermore, a decrease in stability in one-legged squat and supine hip extension was correlated to greater backswing rotation of the pelvis and upper torso. These three tests may provide useful information when deciding whether stability training should be considered to overcome specific technical shortcomings.

Keywords: Golf, swing kinematics, stability

INTRODUCTION

Today's elite golfers often make use of a network of specialists to improve their performance. Two of these specialists are the physiotherapist and the technical golf coach. The former checks players for physical deficits and the latter for technical shortcomings. It is commonly believed that certain physical enhancements can improve the swing technique (Geisler, 2001). Stability may be an important physical attribute for both injury prevention and performance enhancement (Booth, 2005).

Stability is achieved by both passive (through the osseous and ligamentous structures) and active stiffness (through the muscles) (Panjabi, 1992). Stability training is thought to enhance the neuro-muscular system's ability to control the joints (Bliss & Teeple, 2005). Stability tests can be used to identify the possible need to improve stability through training programs (Norris, 2000; Sahrman, 2002).

Impact and ball flight accuracy may be improved by controlling the linear displacement of the hip and upper torso during the swing. Fujimoto-Kanatani (1995) investigated the kinematics of 13 professional golfers and found that they kept their right knees and hip points relatively

stationary in the backswing. Furthermore, a smaller linear displacement of the upper spine (C7) in the downswing was found to be correlated to more accurate impact, when seven university team players' swings were measured (Wang, Yan, & Shiang, 2007). These strategies may constrain the degrees of freedom and provide a stable rotational axis.

Club head speed at impact affects the initial ball velocity and thus the striking distance. Increased ball velocity is related to the upper torso–pelvic separation at the top of the backswing and maximum upper torso–pelvic separation during the downswing (Myers et al., 2007). Such separation may require lower body stability (ability to resist upper torso rotation).

Stability may be an important fitness parameter in improving impact accuracy and club head speed. However, the relationship between stability and swing kinematics has not been investigated. The aim of this study was therefore to investigate (1) the association between stability and the linear displacement of the pelvis and upper torso, and (2) the association between stability and the angular kinematics of the pelvis and upper torso at the top of the backswing and at the moment of maximum upper torso–pelvic separation during the downswing.

METHOD

Participants

Eleven male amateur high school players (height 1.80 ± 0.05 m; body mass 70 ± 6 kg; age 17 ± 1 years; handicap -0.4 ± 1.8 strokes) and seven female amateur high school players (height 1.64 ± 0.07 m; body mass 59 ± 11 kg; age 16 ± 1 years; handicap -3.4 ± 2.1 strokes) volunteered to take part in the study. Written informed consent was obtained from parents or guardians of the participants, as well as the participants themselves.

Measurement of stability

An experienced physiotherapist tested the players' stability. The kinematic measurements of their swings were made after his assessment. The same physiotherapist assessed all subjects, to increase the reliability. Four tests were used to investigate the stability of the lower body and trunk, in the sagittal, frontal, and transversal planes. (More information on the tests can be found in Elphinston, 2006; Norris, 2000; and Sahrman, 2002). The tests used were supine hip extension, one-legged squat, prone bridge and sitting hip flexion. Each test had four levels of difficulty (0 to 3 points). All subjects tried to perform the easiest test first. The level of difficulty was increased if they succeeded.

Supine hip extension: The subjects lay supine with a 90-degree hip flexion. One or two legs were slowly (at approximately 20 degrees per second) lowered towards the ground. The objective was to maintain the pelvic tilt while exerting constant pressure, with the lumbar spine toward the physiotherapist's hand, which was held between the lumbar spine and the floor. The knee flexion was manipulated to change the degree of difficulty.

0 p: Subject succeeded in lowering both legs at the same time, with a 20-degree knee flexion

1 p: Subject succeeded in lowering both legs (one leg at a time), with a 20-degree knee

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flexion. The opposite hip was held passively in flexion.

2 p: Subject succeeded in lowering both legs (one at a time), with a 90-degree knee flexion. The opposite hip was held passively in flexion.

3 p: Failed.

One-legged squat: The subjects supported their body mass standing on one leg. In an attempt to make a full squat, they were instructed to make contact between hamstring and calf and then extend the knee fully again. The knee should move in the direction of the foot without shaking, and the hip should maintain its frontal plane position without a lateral tilt (Trendelenburg sign). The difficulty was adjusted by changing the support for the non-squatting leg.

0 p: Subject succeeded in squatting with both legs (one at a time) without support. The subject was standing on a small bench and had the free leg pointing forward in the air without support.

1 p: Subject succeeded in squatting with both legs (one at a time) with unstable support. The non-squatting leg was extended at the hip and flexed at the knee, with the foot supported on a Swiss ball.

2 p: Subject succeeded in squatting with both legs (one at a time) with stable support. The non-squatting leg was extended at the hip and flexed at the knee, with the foot supported on a stool.

3 p: Failed.

Sitting hip flexion: The subjects sat with a 90-degree hip flexion and a 90-degree knee flexion with their spine extended. The task was to perform a unilateral hip flexion so that one foot lifted 10 cm. The pelvis and spine should remain in a fixed position without lateral deviation, extension, or rotation.

0 p: Subject succeeded on both sides when sitting on a Swiss ball with one foot on the ground.

1 p: Subject succeeded on both sides when sitting on a table without one foot on the ground.

2 p: Subject succeeded on both sides when sitting on a chair with one foot on the ground.

3 p: Failed.

Prone bridge: The subjects assumed a prone position on the floor with their toes and forearms on the ground. The elbows were placed beneath the shoulders. The starting position was held without a large pelvic flexion.

0 p: Subject succeeded in maintaining a stable position while diagonally lifting one arm and one leg and holding the position for 10 s.

1 p: Subject succeeded in lifting one leg only for 10 s.

2 p: Subject succeeded in maintaining the starting position for 10 s.

3 p: Failed.

Measurement of swing kinematics

Three-dimensional data regarding the participants' swings were collected using a Polhemus Liberty electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA), sampling at 240

Hz. A transmitter, which contains three orthogonal coils (solenoids), generates three different electromagnetic fields. Sensors, which also contain three orthogonal coils, record the magnetic flux in the three different fields. The magnetic flux generates currents used to calculate a vector defining the direction and strength of the magnetic field at the location of the sensor. Dedicated software computes the position and orientation of the tracking sensors. According to the manufacturer, the static accuracy is 0.076 mm RMS for the x, y, and z directions and 0.15° RMS for sensor orientation. The orientation of the right-handed orthogonal global frame (G) was such that the positive X-axis was parallel to the target line and pointing backwards from the target, the positive Z-axis pointed vertically upwards, and the positive Y-axis pointed forwards for a right-handed golfer. The measurements were made with the subject standing on a synthetic golf mat positioned next to the transmitter.

Participants performed a warm-up session of their choice, which also served as a habituation period. Generally, the warm-up lasted approximately 10 minutes and involved hitting golf balls. Following the habituation period, three sensors mounted on a harness were attached to each participant at the following locations: (1) the lumbo-sacral joint; (2) between the shoulders at the level of the third thoracic vertebra; and (3) the dorsal part of the left hand (secured under the golf glove).

Following the collection of data from a static trial, in which the participant was required to stand in the anatomical position (parallel to the target line), spatiotemporal data were collected as the participants performed three swings with their own driver.

Kinematic analysis

The raw data were smoothed using a second-order, bidirectional, low-pass Butterworth filter with a cutoff frequency of 12 Hz. To analyze the motion of the pelvis and upper torso, a local frame was attached to each segment. The directions of the three axes of each frame were assigned so as to approximate the different anatomical axes of rotation for each segment. This was accomplished by determining rotation matrices for the static alignment trial, in which the segment axes were aligned with the global frame. These rotation matrices were then applied to each sampling interval in the swing trials.

The local x-axis was projected onto the horizontal plane, to describe the rotation of the pelvis and upper torso. Rotation in the horizontal plane was measured as the angle between the projection of the local x-axis and the global X-axis (counter-clockwise rotation was defined as positive). Linear displacements were calculated in all three directions and are represented in relation to the global frame. Sway was defined as the linear displacement along the X-axis, thrust along the Y-axis, and lift along the Z-axis. All linear displacements at address were defined as zero.

Phase and event definitions

The swing was divided into two phases defined by three events. The address position was defined at the moment just before the initial movement of the club away from the target. The top of the backswing was determined as the moment of maximum pelvic clockwise rotation. The backswing was defined as the time between the start of the backswing and top of the backswing, the

downswing as the period between the top of the backswing and the instant that the left hand returned to its address position (impact).

Statistical analysis

Kinematic data from the three trials for each player were averaged. The mean and standard deviation for each parameter were then calculated for the group of 18 participants. Nonparametric Spearman pair-wise correlations were used to examine the relationships between stability tests and swing kinematics, as the conditions for using a parametric test were not met. Significant correlations are presented at $P < 0.05$ and $P < 0.01$. All statistical analysis was performed using SPSS 15.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Table 1 lists the correlation coefficients between stability test scores and linear displacement. Spearman's rho revealed that upper torso sway was significantly correlated with prone bridge and one legged squat. Coefficients of determination (r^2) for these associations were as follows: Upper torso sway–Prone bridge 0.41; Upper torso sway–One-legged squat 0.28.

Table 1. Correlation coefficients between stability test scores and pelvic and upper torso linear displacement.

	Sitting hip flexion	Prone bridge	Supine hip extension	One-legged squat
<i>Backswing</i>				
Pelvic Sway (cm)	0.30	0.13	0.31	-0.16
Upper Torso Sway (cm)	0.24	0.64**	0.37	0.53*
Pelvic Thrust (cm)	0.14	0.35	0.36	0.29
Upper Torso Thrust (cm)	0.22	0.27	0.10	0.21
Pelvic Lift (cm)	-0.23	-0.09	-0.08	-0.13
Upper Torso Lift (cm)	-0.14	-0.11	-0.17	-0.31
<i>Downswing</i>				
Pelvic Sway (cm)	-0.23	-0.20	0.09	0.30
Upper Torso Sway (cm)	-0.18	-0.44	-0.29	-0.42
Pelvic Thrust (cm)	-0.02	-0.11	-0.14	-0.37
Upper Torso Thrust (cm)	0.35	-0.06	-0.18	-0.14
Pelvic Lift (cm)	0.26	0.15	0.16	-0.01
Upper Torso Lift (cm)	0.15	0.23	0.09	0.03

* $P < 0.05$ (2-tailed)

** $P < 0.01$ (2-tailed)

Table 2 lists the correlation coefficients between the stability test scores and angular kinematics. Pelvic rotation at the top of the backswing was significantly related to the test score on supine hip extension and one-legged squat, with coefficients of determination of 0.26 and 0.45, respectively. Upper torso rotation at the top of the backswing was also significantly related to the test score on supine hip extension and one-legged squat, with coefficients of determination of 0.24 and 0.45, respectively. No significant correlations were found between upper torso–pelvic separation and stability test scores.

Table 2. Correlation coefficients between stability test scores and pelvic and upper torso angular kinematics.

	Sitting hip flexion	Prone bridge	Supine hip extension	One-legged squat
<i>Top of backswing</i>				
Pelvic Rotation (°)	-0.27	-0.28	-0.51*	-0.67**
Upper Torso Rotation (°)	-0.05	-0.03	-0.49*	-0.67**
Upper Torso–Pelvic Separation (°)	0.17	0.31	0.20	0.18
<i>Maximum</i>				
Upper Torso–Pelvic Separation (°)	0.04	0.24	-0.11	0.05

* $P < 0.05$ (2-tailed)

** $P < 0.01$ (2-tailed)

DISCUSSION

The purpose of this study was to investigate the relation between stability tests and the linear and angular kinematics of the pelvis and upper torso. The results show that scores obtained from common stability tests are related to both linear and angular kinematics, but not significantly to variables previously associated with improved impact accuracy and club head speed (Fujimoto-Kanatani, 1995; Wang, Yan, & Shiang, 2007).

A decrease in stability in the prone bridge and one-legged squat was associated with upper body sway further away from the target. The prone bridge explained the upper body sway more than the one-legged squat ($r^2 = 0.41$ vs. $r^2 = 0.28$). The long lever between the elbow and toes when performing the prone bridge indicates that it is a good test of sagittal plane stability, which may be necessary to control upper torso sway during the swing.

A decrease in stability in the supine hip extension and one-legged squat was associated with an increase in both pelvic and upper body backswing rotation. A decrease in hip rotation may decrease the upper torso rotation. An increase in both lower body stability and upper body flexibility is probably needed to increase the upper torso–pelvic separation during the backswing. The one-legged squat provided the largest explanation of the rotation of the pelvis and upper torso

($r^2 = 0.45$ and $r^2 = 0.45$). It may therefore be the best choice for stability testing when too large a pelvic rotation is detected in the backswing. However, other stability tests must also be investigated.

Both movement plane and speed differ between the pelvic motion during the one-legged squat and the downswing. The high forces and torques associated with the downswing (Okuda, Armstrong, Tsunezumi, & Yoshiike, 2002; Nesbit & Serrano, 2005) indicate a high demand on stability, providing a stable proximal base for the distal segments to pull from. Stability tests with movement in the transverse plane at higher speeds may therefore be valuable

In conclusion, stability is associated with swing kinematics as measured here. Physiotherapists working with high school golf players may use the one-legged squat to investigate stability if players are over-rotating their lower body during the backswing or have a large upper body sway. They may also use the supine hip extension when players are over rotating, and the prone bridge test when players are swaying in the backswing. Future studies on training should investigate whether an increase in stability in the one-legged squat and prone bridge tests improves impact and ball flight accuracy. Furthermore, the effect of lower body stability and upper body flexibility training on club head speed and driving distance should be investigated.

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