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A Comparison of Physical Characteristics and Swing Mechanics Between Golfers With and Without a History of Low Back Pain

Golf is an athletic activity enjoyed by people of all ages and skill levels. There are more than 55 million golfers around the world, and the number of participants is increasing worldwide.⁹ Because golf is not an intense activity, it is especially suitable for older people to stay active and improve their health. Among golf injuries, low back pain (LBP) is the most common complaint for

both professional and amateur golfers.^{11,30} Low back injuries result in disability that prevents participation in golf for 10 weeks per incident, on average,¹⁸ and may significantly impact an elderly

golfer's health. Physical therapists are treating golfers with LBP and are being asked what can be done to hasten a return to golf without pain. As such, it is essential to understand why low back in-

juries occur frequently among golfers, so that healthcare professionals can provide better treatment, as well as suggestions for injury prevention.

The golf swing produces considerable mechanical forces, including compressive force, shear force, and rotational moments to the lumbar spine due to rapid trunk bending and rotation.²⁰ Improper swing mechanics and an inappropriate combination of muscle strength, flexibility, coordination, and balance can produce even larger and possibly injurious forces to the lumbar spine.^{20,40} These forces may lead to the development of mechanical LBP, which is generally localized to the lumbar area and associated with significant muscle spasms.²⁰ It may begin gradually with periodic episodes but can eventually lead to permanent disability.²⁰

Several motions during the golf swing may contribute to low back injury.^{14,20,27} In the modern backswing, the upper torso rotates against restricted pelvic rotation to produce maximum angular difference between the shoulders and hips ("X-factor"). This movement creates a tightly coiled torso that is capable of storing elastic energy for subsequent release during the downswing, leading to maximum club head speed at impact.³² Lindsay and Horton²⁷ observed that golf-

• **STUDY DESIGN:** Controlled laboratory study using a cross-sectional design.

• **OBJECTIVES:** To examine the kinematics and kinetics of the trunk and the physical characteristics of trunk and hip in golfers with and without a history of low back pain (LBP).

• **BACKGROUND:** Modified swing patterns and general exercises have been suggested for golfers with back pain. Yet we do not know what contributes to LBP in golfers. To create and validate a low back-specific exercise program to help prevent and improve back injuries in golfers, it may be valuable to understand the differences in biomechanical and physical characteristics of golfers with and without a history of LBP.

• **METHODS:** Sixteen male golfers with a history of LBP were matched by age and handicap with 16 male golfers without a history of LBP. All golfers underwent a biomechanical swing analysis, trunk

and hip strength and flexibility assessment, spinal proprioception testing, and postural stability testing.

• **RESULTS:** The group with a history of LBP demonstrated significantly less trunk extension strength at 60°/s and left hip adduction strength, as well as limited trunk rotation angle toward the nonlead side. No significant differences were found in postural stability, trunk kinematics, and maximum spinal moments during the golf swing.

• **CONCLUSION:** Deficits observed in this study may affect a golfer's ability to overcome the spinal loads generated during the golf swing over time. Exercises for improving these physical deficits can be considered, although the cause-effect of LBP in golfers still cannot be determined. *J Orthop Sports Phys Ther* 2010;40(7):430-438. doi:10.2519/jospt.2010.3152

• **KEY WORDS:** balance, flexibility, golf swing, proprioception, strength

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ers with LBP tend to rotate their upper body beyond their physical limits of trunk rotation during the backswing. This over-rotation may result in an uncompensated rotational moment to the lumbar spine, stressing soft tissues of the lumbar region and causing tissue damage over time. Furthermore, many teaching and touring professionals believe that finishing the golf swing with trunk hyperextension (“reverse C” position) allows the golfer to efficiently absorb the power released during the downswing, thereby increasing driving distance.¹⁴ However, excessive extension of the spine may result in increased anteriorly directed shear force on the lumbar spine.¹⁴

In addition to trunk biomechanics, muscle strength^{2,25,34} and flexibility^{2,42} of the trunk and hip, spinal proprioception,^{16,36} and postural stability^{28,31} are also potential factors contributing to the relationship between trunk motion and low back injuries. Deficient spinal proprioception can affect normal neuromuscular control of the spine and alter the sense of body position and movement.²⁴ In fact, a few researchers have reported that individuals with LBP present with proprioception deficits in trunk flexion.^{4,16,36} It is not clear whether golfers with a history of LBP present with proprioception deficits. Postural stability is also potentially impaired in the presence of impairment in strength, coordination, or effective coupling of muscles in the lumbar and pelvic region.²⁸ Previous studies revealed that individuals with LBP demonstrated increased sway velocity and range.^{28,31} Similar findings may exist in golfers experiencing LBP.

Modified swing patterns and exercise for golf have been suggested to reduce the spinal load that creates low back injury. However, without knowing the differences in swing mechanics and the physical characteristics between golfers with and without a history of LBP, it is difficult to design an appropriate, low back-specific, swing or exercise program for the treatment or prevention of back injuries in golfers. Therefore, the purpose of this

TABLE 1		CHARACTERISTICS OF THE PARTICIPANTS	
	With LBP History*	Without LBP*	P Value
Age (y)	48.6 ± 7.4	47.9 ± 8.3	.805
Height (cm)	178.2 ± 5.4	181.4 ± 8.0	.196
Mass (kg)	88.3 ± 18.2	87.5 ± 9.6	.882
USGA handicap	9.1 ± 4.6	9.5 ± 4.8	.847
Modified Oswestry score (%)	45.3 ± 18.2		
<i>Abbreviations: LBP, low back pain; USGA, United States Golf Association.</i>			
<i>* Data are mean ± SD (n = 16).</i>			

study was to examine the kinematics and kinetics of the trunk during the golf swing in golfers with and without a history of LBP and also compare the physical characteristics of the trunk and hip between groups. We hypothesized that golfers with a history of LBP would demonstrate differences in maximum upper torso-pelvic separation normalized to trunk rotation flexibility, crunch factor, trunk extension angle, lumbar rotation velocity, and spinal moments at the L5-S1 spinal level, compared to golfers without a history of LBP. We also hypothesized that golfers with and without a history of LBP would demonstrate differences in trunk and hip strength and flexibility, trunk repositioning sense, and postural stability.

METHODS

Participants

SIXTEEN MALE GOLFERS WITH A HISTORY of mechanical LBP aggravated by golf within the past 2 years were matched by age and handicap to 16 male golfers with no history of LBP. The sample size was estimated based on the data on normalized maximum upper torso-pelvic separation published by Lindsay and Horton,²⁷ using a 1-tailed *t* test, α level of .05, and desired power of 0.8. All golfers were right-handed, with a United States Golf Association handicap less than 20. Demographic data for all participants are presented in **TABLE 1**. Golfers with a history of LBP had their symptoms generally localized over the right or central lumbosacral region. Their worst epi-

sode of LBP within the past 2 years prior to testing had a modified Oswestry Disability Questionnaire¹² score greater than 24% and required conservative treatment; but all participants were pain free at the time of testing.¹⁹ Participants with a history of previous back surgery, vertebral compression fracture, neurologic deficits, current lower extremity symptoms, current lumbar radiculopathy or a history of the condition, and symptoms of vertigo or dizziness were excluded. This study was approved by the University of Pittsburgh Institutional Review Board. Informed consent was obtained from participants prior to participation, and the participants’ rights were protected.

Assessments

Kinematics and spinal loads of the trunk were assessed using the Vicon Motus system (Vicon, Centennial, CO) with 8 high-speed (120-Hz) optical cameras, interfaced with 2 force plates (1200 Hz) (Kistler Instrument Corp, Amherst, NY). Participants were fitted with reflective markers placed over the following landmarks bilaterally: the posterior heel, lateral malleolus, second metatarsal head, femoral epicondyle, anterior superior iliac spine, sacrum, tips of acromions, and T4 spinous process. Four markers were attached to wands 0.09 m from the skin and secured with Velcro straps lateral to the midpoint of the thighs and lower legs. Two markers were placed on each side of the body at the L5-S1 level to locate the center of the lumbosacral joint. Three markers were used to define the upper

lumbar spine (right and left ribs and the spinous process at the T12-L1 level of the spine) and secured to the body using athletic prewrap. Two markers were placed on the golf club to identify the phases of the golf swing, and upper extremity markers were also applied for data collection as part of a separate study (FIGURE).

Each participant performed a self-selected warm-up of swings, stretches, and practice shots. A static calibration trial was collected for each participant prior to testing. Participants were instructed to stand in anatomical position with their feet shoulder width apart in the capture volume. After the static trial, participants were asked to maximally rotate their trunk toward the nonlead side, and the rotational angle was measured to obtain a theoretical limit of backswing movement in the same standing position. This measurement was taken for normalizing the X-factor, to assess if golfers rotated their upper body beyond their physical limitation of trunk rotation during the back swing. Participants hit golf balls with their own driver to better replicate their actual swing pattern while playing. Participants stood with 1 foot on each force plate and hit 10 shots off an artificial turf mat into a golf simulator (AboutGolf; AboutGolf Limited, Maumee, OH) screen located 5 m away.

Trunk and hip muscle strength was assessed with the Biodex System III (Biodex Medical Inc, Shirley, NY). Isokinetic strength of trunk rotation and trunk flexion/extension were tested in a seated position and in a semistanding position, respectively. Participants performed 5 repetitions at 60°/s and 120°/s for both trunk rotation and flexion/extension. Isometric strength of hip abduction, adduction, flexion, and extension was measured in a combination of sidelying and supine position. Each participant performed 3 isometric contractions for 5 seconds in each direction on both lower extremities. The peak torque-body weight ratio [(Nm/kg) × 100] was used for reporting trunk and hip strength, as well as strength ratios between muscle groups. Because the hip muscles play an important role in

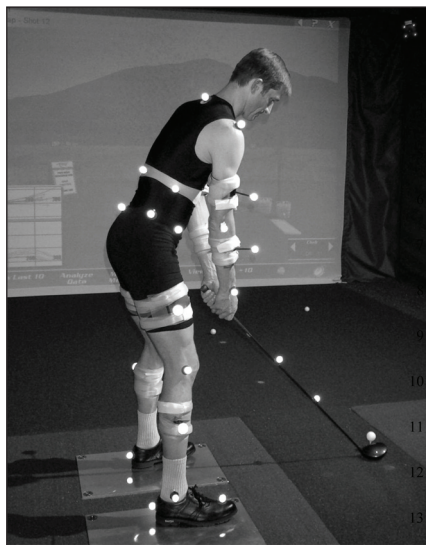


FIGURE. Three-dimensional biomechanical analysis of the golf swing.

maintaining lower body stability during the golf swing, while the trunk muscles produce rapid trunk movement around this stable lower body, isometric hip muscle strength and isokinetic trunk muscle strength were selected for the strength assessments, respectively.

Trunk repositioning error was measured using an electromagnetic tracking device (The MotionMonitor; Innovative Sports Training, Chicago, IL). While proprioception is a broader concept that describes additional submodalities, including active and passive kinesthesia and perception of tension, spinal position sense is one method frequently used for assessing spinal proprioception.³⁸ Spinal position sense has been assessed in previous studies to assess differences in back proprioception between individuals with and without LBP.^{36,41} Participants stood with their feet shoulder width apart and arms crossed at their chest. To control pelvic motion, the participants were partially immobilized with a customized pelvic-stabilizing apparatus. Two sensors were attached to the participant's skin at the first segment of the thoracic and sacral spine (T1 and S1) using double-sided tape and surgical tape (3M Health Care, St Paul, MN) for measuring spinal position. The participants were asked to

perform maximal trunk flexion, extension, lateral bending, and rotation to both the left and right sides to assess maximum trunk range of motion (ROM) for each movement direction prior to testing procedures. Participants were then blindfolded to eliminate visual input. Participants actively moved to a target position of 80% of the maximum ROM for a specific direction and held the position for 4 seconds. Audio feedback (a steady beep) from the MotionMonitor was provided to help participants maintain the target position within a 2° range, the target ±1°. The participant returned to the neutral position and then attempted to reproduce the target position without assistance. The participant verbally indicated when the target position had been reached, and the investigator immediately stop-marked that location in the computer to determine the reposition angle. Absolute error for trunk reposition sense was calculated as the absolute difference between the target angle and the reposition angle. Six trials were taken for each of the 6 directions of trunk movement. The order of testing each direction of trunk movement was randomly assigned for each participant to prevent potential effects of fatigue. The reliability using intraclass correlation coefficients (ICCs) of trunk ROM measurement in 6 directions was between 0.842 and 0.985. The standard error of measurement in trunk repositioning error for all directions was between 0.2° and 1.0°.

Hip ROM was measured using a standard goniometer by an experienced physical therapist. Objective measurement of flexibility with the FABER test was made by measuring the distance from the lateral epicondyle of the femur to the horizontal table surface with the hip in flexion, abduction, and external rotation, while the ipsilateral ankle rested on the contralateral knee, without downward pressure applied to the tested limb.⁴² Hamstring flexibility was evaluated using the active knee extension test, where maximum knee extension was measured with the hip at 90° of flexion.¹³ The re-

liability (ICC) of all hip ROM measurement was between 0.820 and 0.995.

Postural stability was assessed using a Kistler force plate (Kistler Corporation, Amherst, NY) and a protocol similar to the one used by Goldie et al.¹⁷ Each participant was asked to complete a barefoot single-limb standing balance task for each lower extremity under 2 visual conditions (eyes open and eyes closed). Three 10-second trials were performed for each lower extremity under each visual condition. The participants were instructed to remain as erect as possible, with hands on hips. Participants were instructed to focus on a target located approximately 2 m in front of them at eye level during the testing session with eyes open. During the testing session with eyes closed, the participants were instructed to focus on the target for balance first then close their eyes for data collection. Sway velocity of the center of pressure while standing on 1 lower extremity was calculated for statistical analysis using total sway distance divided by testing time.

Data Analysis

Kinematic data of the golf swing were filtered using an optimized cutoff frequency.²² Angular difference between the shoulders and pelvis (upper torso-pelvic separation) during the golf swing was calculated by subtracting the pelvic rotation angle from the upper torso rotation.^{26,32} The trunk segment was defined as the middle of the 2 shoulder markers to the middle of the markers at L5-S1 level. The lumbar segment was defined as the middle of the markers on the side of the ribs at T12-L1 spinal level to the middle of the markers at L5-S1 level. Trunk anterior/posterior tilt angle and lumbar lateral bending angle were calculated with respect to the pelvic anterior/posterior tilt and the pelvis. Rotation velocity of the lumbar spine was the change of the angular difference between the T12-L1 level and pelvis over time. The instantaneous product of lumbar lateral bending angle and spinal rotation velocity was calculated for crunch factor.

Raw analog data from the 2 force plates were used for the calculation of the

TABLE 2		TRUNK KINEMATICS AND KINETICS DURING THE GOLF SWING AND ESTIMATED DRIVING DISTANCE		
	With LBP History*	Without LBP*	P Value	
Kinematic variables				
Maximum upper torso-pelvic separation (°)	46 ± 8	50 ± 6	.092	
Maximum trunk rotation angle toward nonlead side (°) [†]	45 ± 6	52 ± 6	.004 [‡]	
Normalized maximum upper torso-pelvic separation (%) [§]	104 ± 21	98 ± 13	.368	
Maximum trunk extension angle (°)	2 ± 8	4 ± 7	.438	
Maximum lumbar spinal rotation velocity (°/s)	218 ± 43	217 ± 54	.981	
Maximum spinal moments at L5-S1				
Maximum flexion moment (%BW × BH)	-79 ± 4.4	-75 ± 4.3	.793	
Maximum extension moment (%BW × BH)	0.9 ± 2.2	0.1 ± 1.2	.209	
Maximum left bending moment (%BW × BH)	-5.2 ± 3.3	-4.4 ± 2.4	.472	
Maximum right bending moment (%BW × BH)	4.4 ± 2.4	4.9 ± 2.9	.546	
Maximum back rotation moment (%BW × BH)	-3.8 ± 2.2	-4.3 ± 2.4	.545	
Maximum forward rotation moment (%BW × BH)	1.7 ± 1.1	1.5 ± 0.9	.524	
Estimated driving distance (m)	206.8 ± 27.8	220.3 ± 24.6	.156	
<p><i>Abbreviations: BH, body height; %BW, percent body weight (peak torque [Nm]/body weight [kg] × 100); LBP, low back pain.</i></p> <p><i>* Data are mean ± SD (n = 16).</i></p> <p><i>[†] Maximum trunk rotation angle was measured actively in neutral standing position.</i></p> <p><i>[‡] P < .01 (significant difference between groups after Bonferroni correction).</i></p> <p><i>[§] Normalized maximum upper torso-pelvic separation (maximum upper torso-pelvic separation/maximum trunk rotation angle toward nonlead side × 100).</i></p>				

spinal moments around the 3 anatomical axes at L5-S1, using an inverse-dynamics procedure. The bottom-up dynamic 3-D linked segment model used in this study consisted of 7 segments: bilateral feet, lower legs, thighs, and pelvis.²³ Anthropometric data, including segment length, mass,¹ moment of inertia,^{5,44} and center of mass,⁷ were measured from each participant and calculated. Three-dimensional coordinates of markers and joint centers and ground reaction forces were exported from the Vicon Motus software to a customized Matlab program (Version 6.0, Release 12; The Mathworks, Inc, Natick, MA) for the calculation of spinal moments. Spinal moments on the global axes were converted to the anatomical axes and normalized to the product of the participant's body weight and height.

AboutGolf's Sim Sensor and software were used to determine the best 5 shots of each participant, based on the longest estimated driving distance. Kinematic and kinetic data of each participant's best 5 shots were averaged for data analysis.

Statistical Analysis

Descriptive statistics were analyzed to assess means and standard deviations between the 2 groups. Two-tailed independent *t* tests were used to determine significant differences in swing mechanics, muscle strength and flexibility of the trunk and hips, trunk repositioning errors, and postural stability between golfers with and without a history of LBP. Statistical significance was set at *P* < .05 for all procedures. To control for inflated type I error rate due to the number of tests performed, the Bonferroni correction was applied within groupings of related tests. The groupings are trunk kinematics during the golf swing, isokinetic strength of trunk muscles, isometric strength of hip muscles, flexibility of hips and hamstrings, and trunk repositioning errors. SPSS 11.0 (SPSS, Inc, Chicago, IL) was used for data analysis. In addition, Cohen's *d* was calculated using the means and standard deviations of the 2 groups to determine the effect size of comparisons in physical characteristics.

RESULTS

THE RESULTS OF TRUNK KINEMATICS and kinetics during the golf swing and the estimated driving distance are shown in **TABLE 2**. The group with a history of LBP had significantly less maximum trunk rotation angle toward the nonlead side measured actively in neutral standing position than the group without LBP ($P = .004$). No significant differences were found for the kinematic variables and the maximum moments about the 3 anatomical axes at the L5-S1 level between the 2 groups. There was no significant difference in estimated driving distance between the 2 groups ($P = .156$).

The data for trunk and hip strength are shown in **TABLES 3** and **4**. The group with a history of LBP demonstrated statistically significant less trunk extension strength at 60°/s ($P = .006$) and less left hip adduction strength ($P = .010$) than the group without LBP. While left trunk rotation strength at 60°/s ($P = .023$) was not significantly different between the 2 groups, it had a Cohen's d value of 0.855. Similarly, bilateral hip extension strength ($P = .024$ and $P = .020$ for the right and left lower extremities) was not significantly different between the 2 groups, but demonstrated a Cohen's d value of 0.837 and 0.867 for the right and left lower extremities, respectively.

Active trunk and hip ROM values are shown in **TABLES 5** and **6**. No statistically significant difference was observed in active trunk ROM. Although the group with a history of LBP did not demonstrate significantly less knee extension during the active knee extension tests than the group without LBP ($P = .030$ for right limb, $P = .025$ for left limb), it had a Cohen's d value of 0.849 for right limb and 0.811 for left limb.

The group with a history of LBP did not demonstrate significantly greater trunk repositioning errors. However, the differences in trunk flexion ($P = .014$) had a Cohen's d value of 0.899 (**TABLE 7**). No significant between-group differences were found in center-of-pressure velocity

TABLE 3		ISOKINETIC STRENGTH FOR THE TRUNK MUSCULATURE			
Speed	With LBP History*	Without LBP*	P Value	Cohen's d	
60°/s					
Extension (%BW)	286 ± 56	362 ± 87	.006†	1.039	
Flexion (%BW)	196 ± 34	208 ± 41	.360	0.319	
Right rotation (%BW)	122 ± 37	142 ± 27	.091	0.618	
Left rotation (%BW)	122 ± 30	146 ± 26	.023	0.855	
120°/s					
Extension (%BW)	317 ± 73	352 ± 89	.233	0.430	
Flexion (%BW)	170 ± 38	182 ± 35	.347	0.328	
Right rotation (%BW)	128 ± 40	140 ± 26	.304	0.356	
Left rotation (%BW)	125 ± 32	140 ± 21	.136	0.554	

Abbreviations: %BW, percent body weight (peak torque [Nm]/body weight [kg] × 100); LBP, low back pain.
 * Data are mean ± SD (n = 16).
 † P < .0125 (significant difference between groups after Bonferroni correction).

TABLE 4		ISOMETRIC STRENGTH OF EACH HIP MUSCLE GROUP			
Muscle Groups	With LBP History*	Without LBP*	P Value	Cohen's d	
Abduction					
Right limb (%BW)	136 ± 43	150 ± 23	.249	0.406	
Left limb (%BW)	133 ± 38	157 ± 29	.048	0.710	
Adduction					
Right limb (%BW)	124 ± 34	152 ± 45	.056	0.702	
Left limb (%BW)	124 ± 36	162 ± 42	.010†	0.971	
Extension					
Right limb (%BW)	262 ± 77	316 ± 49	.024	0.837	
Left limb (%BW)	270 ± 71	327 ± 60	.020	0.867	
Flexion					
Right limb (%BW)	64 ± 24	88 ± 37	.033	0.770	
Left limb (%BW)	58 ± 28	80 ± 28	.037	0.772	

Abbreviations: %BW, percent body weight (peak torque [Nm]/body weight [kg] × 100); LBP, low back pain.
 * Data are mean ± SD (n = 16).
 † P < .0125 (significant difference between groups after Bonferroni correction).

tested in single-limb stance with either eyes open or eyes closed (**TABLE 8**).

DISCUSSION

THIS STUDY EXAMINED SWING MECHANICS of the trunk and physical characteristics of the trunk and hip in golfers with and without a history of LBP, for the purpose of identifying differences that may exist between the groups. We hypothesized that golfers with a history of LBP would demonstrate differences in

swing mechanics, trunk and hip strength and flexibility, trunk repositioning sense, and postural stability compared to the golfers with no history of LBP. Our hypotheses were minimally supported by these data.

Golfers with a history of LBP reported an average ± SD modified Oswestry Disability Questionnaire score of 45.3% ± 18.2%, based on their worst episode during the 2 years preceding testing. This suggests that golfers with a history of LBP experienced golf-related mechanical LBP that compromised their ability

TABLE 5

ACTIVE RANGE OF MOTION OF TRUNK MOVEMENTS

Movement	With LBP History*	Without LBP*	P Value	Cohen's d
Flexion (°)	56 ± 12	55 ± 11	.696	-0.087
Extension (°)	26 ± 7	28 ± 8	.372	0.266
Right rotation (°)	43 ± 5	47 ± 7	.111	0.658
Left rotation (°)	41 ± 8	43 ± 8	.326	0.250
Right sidebending (°)	37 ± 7	41 ± 7	.204	0.571
Left sidebending (°)	37 ± 6	40 ± 5	.144	0.543

Abbreviation: LBP, low back pain.
* Data are mean ± SD (n = 16).

TABLE 6

HIP RANGE OF MOTION AND HAMSTRING FLEXIBILITY MEASUREMENTS*

Movement	With LBP History†	Without LBP†	P Value	Cohen's d
Flexion (°)				
Right limb	134 ± 9	137 ± 6	.295	0.392
Left limb	134 ± 9	140 ± 6	.033	0.784
Extension (°)				
Right limb	20 ± 3	20 ± 5	.826	0.000
Left limb	17 ± 5	18 ± 6	.377	0.181
Knee angle during AKET (°)				
Right limb	158 ± 8	164 ± 6	.030	0.849
Left limb	154 ± 10	161 ± 7	.025	0.811
Abduction (°)				
Right limb	28 ± 6	31 ± 6	.273	0.500
Left limb	30 ± 6	33 ± 7	.159	0.460
Adduction (°)				
Right limb	15 ± 4	17 ± 3	.137	0.566
Left limb	15 ± 3	17 ± 5	.198	0.485
Internal rotation (°)				
Right limb	38 ± 8	41 ± 7	.246	0.399
Left limb	39 ± 8	39 ± 8	.948	0.000
External rotation (°)				
Right limb	33 ± 8	38 ± 9	.099	0.587
Left limb	35 ± 8	39 ± 8	.161	0.500
FABER distance (cm)				
Right limb	18.0 ± 4.1	17.3 ± 4.3	.609	0.167
Left limb	19.9 ± 5.2	18.5 ± 4.5	.415	0.288

Abbreviations: AKET, active knee extension test for hamstring flexibility assessment; LBP, low back pain.
* No significant difference between groups after Bonferroni correction (P < .00625).
† Data are mean ± SD (n = 16).

the golf swing, a flexed trunk angle must be maintained to make a proper turn back and return to the ball.¹ This positioning requires strong back extensor muscles to support the upper body, especially during the golf downswing, as rapid and powerful movements generate considerable spinal loads.²⁰ Weak back extensor muscles may not be able to counteract the flexion moment produced by the abdominal muscles, particularly when fatigued after a number of repetitive golf swings or following other golf-related activities that may fatigue trunk extensors.⁸ It may initially seem incongruous that the trunk extensor strength deficit was noted at a slower swing speed, as the velocity of a golf swing is greater than 120°/s. Yet ideal swing mechanics would suggest that the degree of trunk flexion should remain constant throughout the entire golf swing, suggesting an isometric component of the back extensors to stabilize a static flexion posture, while having a dynamic component to assist in rotational velocity. The primary muscles responsible for these differing functional components may be consistent with the local stabilizers (multifidus and transversus abdominus) stabilizing trunk posture, while the global stabilizers (larger erector spinae and obliques) assist the rotation.

Research has suggested that rapid trunk rotation is a potential risk factor associated with LBP, yet it is an important swing characteristic associated with improved golf performance.^{29,32} Adequate trunk rotation strength may be able to overcome spinal loads produced by high-velocity trunk rotation. In addition, hip muscle strength is considered to be important for maintaining normal lumbopelvic-hip stability.^{33,34} Therefore, deficits in trunk rotation strength and hip muscle strength may increase potential risks of LBP during sports activities. Furthermore, it has been suggested that tight hamstrings are associated with LBP,^{21,37} although there has been debate regarding whether tight hamstrings contribute to low back injuries³⁵ or are a compensatory mechanism secondary to pelvic instability.⁴³ Chronic LBP has also

to perform activities of daily living such as standing, walking, or sitting.⁶ While the study design precluded the determination if the between-group differences were the cause or result of a previous history of LBP, these differences may be

important to consider in the design of treatment and/or prevention programs for this population.

In our results, golfers with a history of LBP demonstrated less back extension strength at 60°/s but not at 120°/s. During

TABLE 7

ACTIVE SPINAL REPOSITIONING ERRORS*

Movement	With LBP History [†]	Without LBP [†]	P Value	Cohen's d
Flexion (°)	3.2 ± 1.5	2.1 ± 0.9	.014	0.899
Extension (°)	2.0 ± 1.2	1.9 ± 0.9	.819	0.094
Right rotation (°)	2.9 ± 1.3	2.2 ± 0.7	.066	0.670
Left rotation (°)	2.8 ± 1.6	2.5 ± 0.8	.564	0.237
Right sidebending (°)	2.2 ± 1.0	1.6 ± 0.5	.047	0.759
Left sidebending (°)	2.1 ± 1.1	1.7 ± 0.7	.225	0.433

Abbreviation: LBP, low back pain.

* No significant difference between groups after Bonferroni correction ($P < .0083$).

[†] Data are mean ± SD ($n = 16$).

TABLE 8

**SWAY VELOCITY OF THE COP
IN SINGLE-LIMB STANCE**

Condition	With LBP History*	Without LBP*	P Value
Eyes open			
Right limb	5.1 ± 2.4	5.2 ± 1.5	.883
Left limb	4.3 ± 1.4	5.4 ± 2.3	.121
Eyes closed			
Right limb	10.3 ± 3.6	10.8 ± 4.4	.750
Left limb	10.5 ± 3.5	11.4 ± 2.9	.442

Abbreviations: COP, center of pressure; LBP, low back pain.

* Values are mean ± SD cm/s ($n = 16$).

been associated with proprioceptive deficits in trunk flexion.^{16,36} Proprioception deficits may influence motor programming for neuromuscular control and muscle reflexes that can decrease trunk stiffness responsible for stabilizing the spine.¹⁹

However, among comparisons in trunk rotation strength, hip muscle strength, hamstring flexibility, and trunk repositioning errors between the 2 groups, only left hip adduction strength was observed to have significant deficits in golfers with a history of LBP. It is noteworthy that although left trunk rotation strength at 60°/s, bilateral hip extension strength, bilateral hamstring flexibility, and trunk repositioning errors in flexion in golfers with a history of LBP were not significantly different from the group without LBP, each of these comparisons had a large effect size.

Appropriate flexibility of the trunk and hip is critical for golf proficiency and to prevent low back injuries.^{39,42} Vad et al⁴² reported that golfers with LBP had

decreased lumbar extension, decreased lead hip internal rotation, and increased FABER distance of the lead hip. However, similar findings were not observed in the current study. Participants in the study of Vad et al⁴² were all professional golfers with LBP at the time of testing. Participants in this study were all amateur golfers with a history of LBP but no pain at the time of testing. It is also not known whether the difference in the volume of golf practice and play between professional and amateur golfers resulted in the conflicting findings between the studies. The active pain process may also contribute to the conflicting results.

Postural stability can be affected by the presence of impairment in strength, coordination, and/or effective coupling of muscles in the lumbar and pelvic area.²⁸ Previous research reported that individuals with LBP demonstrated greater postural sway during standing balance tests, especially with increased task complex-

ity.^{28,31} However, golfers with a history of LBP did not show postural instability when compared to the group without LBP. All participants in this study were proficient golfers who may be more physically fit than nonathletic individuals. The balance tests conducted in the current study may not have been sufficiently challenging to differentiate between the 2 groups, especially because the participants were pain free at the time of testing. Future studies could address this limitation by using a dynamic balance assessment to further assess balance deficits.

In the current study, the group with a history of LBP demonstrated less maximum trunk rotation angle toward the nonlead side. This may result in an inability of these golfers to generate maximum upper torso-pelvic separation.³² A greater upper torso-pelvic separation at the beginning of the downswing increases storage of potential energy for maximum club head speed at impact as the potential energy becomes kinetic energy. It was hypothesized that if a golfer generates maximum upper torso-pelvic separation beyond the physical limitation of trunk rotation, particularly when trying to generate greater than normal power in the golf swing, excessive stresses may contribute to ongoing irritation of spinal structures, leading to the development of low back injury.²⁷ The results of the current study revealed that the maximum upper torso-pelvic separation normalized by the maximum right trunk rotation angle in neutral position was not significantly different between golfers with and without a history of LBP. Unlike the previous study, in which participants were tested at a driving range, golfers in this study were tested in a laboratory environment that might have encouraged them to swing within themselves, avoiding the overrotation condition. Therefore, the hypothesis that rotating upper torso beyond physical limitation of trunk rotation during the backswing may contribute to lower back injury is not supported and needs further exploration. However, improving flexibility of trunk rotation for golfers with a

history of LBP may decrease the stress to their back structures. An alternative strategy may be to incorporate a shortened backswing to protect an individual with less rotational movement, as some data suggest that reducing the length of backswing may reduce force on the spine, with no significant loss of club head velocity.⁴

Rapid spinal rotation velocity could produce considerable amounts of spinal load during the golf swing, resulting in the development of low back injuries.²⁰ Because low back injuries in golfers are thought to be caused by the forces that are associated with lumbar movements, lumbar spinal rotation velocities were compared for both groups of golfers in this study. Similar to the study of Lindsay and Horton,²⁷ no significant differences in spinal rotation velocities were observed between golfers with and without a history of LBP. These results may indicate that although rapid spinal rotation during the downswing can produce large spinal load, they are not likely to be the sole contributor to low back injuries. Rapid spinal rotation during the golf swing, combined with physical limitations, however, may play a role in golf specific injury.

Trunk hyperextension at the end of golf swing has been considered a risk factor for low back injuries by increasing spinal forces.¹⁴ However, golfers with a history of LBP did not demonstrate a significantly different trunk extension angle at the end of swing than golfers without LBP in this study. Lindsay and Horton²⁷ observed that golfers with LBP demonstrated less maximum trunk extension angle at the end of swing than the golfers without LBP. These authors described this finding as a potential protective mechanism adopted by injured golfers to prevent LBP, as the golfers in their study were tested with existing pain.²⁷ In the current study, golfers with a history of LBP were tested with no current musculoskeletal or neurological symptoms. They might have avoided hyperextending their back to prevent the occurrence of LBP, or the trunk extension angle at the end of golf swing might not be a relevant

physical characteristic to consider.

Unlike the study of Hosea et al,²⁰ which used mathematical models and myoelectric activity of trunk muscles to evaluate spinal loads during the golf swing, this study used a bottom-up dynamic 3-D linked segment model. The group with a history of LBP demonstrated similar maximum spinal moments at L5-S1 during the golf swing compared to the healthy group in this study. Although trunk muscle activity was not included in the calculations of the spinal loads, the results may provide valuable information and may imply that golf swing can generate similar amount of spinal moments for both groups of golfers.

Previous studies have shown that different warm-up exercises may have different effects on club head speed, distance, accuracy, and consistent ball contact.^{10,16} It is a limitation of this study that every golfer performed self-selected warm-up exercise that might have affected the results of this study. A standardized warm-up would be a better choice for future studies.

Finally, it must be considered that very few physical characteristics examined in this study were found to be significant. A case can be made for how weak trunk extension and reduced nonlead side rotation could mechanically impact spinal structures contributing to LBP and how weak lead-side hip adductors can fail to adequately stabilize the pelvis during weight bearing in the downswing. Even so, it is possible that each of these factors is noncontributory, which is supported by the small number of characteristics found to be significant out of the high number of characteristics examined.

Additionally, as previously discussed, a number of factors were not statistically significant yet demonstrated large effect sizes. This fact may suggest that the statistical procedures incorporated in the analysis were fairly conservative, reducing the likelihood of finding significance when true differences did exist. Further research needs to be performed with larger sample sizes to examine these hypotheses.

CONCLUSION

THE RESULTS OF THIS STUDY DEMONSTRATED that golfers with a history of LBP had decreased trunk extension strength at 60°/s and left hip adduction strength. The group with a history of LBP also had limited trunk rotation angle toward the nonlead side. These deficits may affect dissipation of the spinal loads generated by the golf swing over time. Knowledge about the differences in swing mechanics and physical characteristics that may contribute to the low back injuries is still vague. Low back injury in golfers may result from a single swing or develop gradually from chronic loading due to swinging a club with suboptimal physical fitness. Both can contribute to permanent disability. It is unknown if the deficiency found in the group with a history of LBP in the current study contributed to the back injury or is the result of the injury. Regardless, these physical characteristics should be carefully evaluated when examining golfers with a history of LBP. ●

KEY POINTS

FINDINGS: Golfers with a history of LBP demonstrated decreased trunk extension strength at 60°/s and left hip adduction strength, as well as limited trunk rotation angle toward the nonlead side. Trunk kinematics and maximum spinal moments during the golf swing were similar between golfers with and without a history of LBP.

IMPLICATION: A comprehensive exercise program that focuses on trunk extension strength at slow speed, left hip adduction strength, and backswing rotational ROM may improve the observed deficits noted in this study and may impact the incidence or recurrence of LBP as well.

CAUTION: Whether the deficiencies found in the group with a history of LBP contributed to the back injury, are the result of the injury, or are even clinically relevant has not been determined.

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