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Research article

Deficits in the Star Excursion Balance Test and Golf Performance in Elite Golfers with Chronic Low Back Pain

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Abstract

The purpose of this study was to investigate whether low-handicap elite golfers with chronic low back pain (CLBP) exhibit deficits in dynamic postural control and whether CLBP affects golfers in terms of their golf swing parameters. A total of fifteen Division 1 college golfers were recruited as participants. Of these, six of whom experienced CLBP, while the remaining participants were healthy. In this study, CLBP was defined as experiencing chronic pain symptoms for more than six months. The Star Excursion Balance Test (SEBT) was administered to examine dynamic posture control in both groups. The TrackMan Golf Launch Monitor Simulator was used to collect data on the performance parameters of the swing of the participants. The results for both feet in the medial, lateral, posterior, posteromedial, and posterolateral directions indicated that the CLBP group scored lower than the control group. However, the CLBP group scored higher for the right foot in the anterolateral direction. The parameters for the club speed and ball carry of the CLBP group were lower than those of the control group. Further, the CLBP group exhibited a more upright swing plane relative to the control group. Taken together, our findings suggest that SEBT may be feasible and highly accessible to assess golf swing performance of elite players with CLBP.

Key words: Dynamic postural control, low-handicap golfer, overuse, swing plane.

Introduction

Low back pain is a common problem in the musculoskeletal system of athletes. According to previous studies, the prevalence of low back pain in athletes across various types of sports is anywhere between 33% and 84% (Farahbakhsh et al., 2018). Golfers are more susceptible to low back injury (prevalence: 34%-42%) as compared to other injuries (Fradkin et al., 2003; McCarroll et al., 1990). Previous studies have also shown that overuse is the cause of 82.6% of low back injury cases (Gosheger et al., 2003). In particular, skilled golfers (low handicap golfers) require constant practice to maintain their skill and perform well in tournaments. The incidence rate of lower back injury among professional and nonprofessional golfers (particularly low handicap golfers) is 55% and 35% (Cole and Grimshaw, 2016), respectively, and thus warrants attention. Furthermore, recent research has demonstrated that non-athlete adults have deficits in dynamic postural control caused by chronic low back pain (CLBP) (Ganesh et al., 2015). However, there have been no studies investigating whether CLBP affects dynamic postural control and swing performance in golfers.

Chronic low back pain (CLBP) has been defined as low back pain lasting for more than three months after the occurrence of a low back injury (Bogduk, 2004). Deficits in postural control caused by CLBP have been attributed to the dysfunction of the muscle spindle around the spine (Brumagne et al., 2000). In addition, altered proprioception and reduced postural control may increase muscle tension and delay muscle recruitment (Ershad et al., 2009). Ganesh et al. (2015) adopted the Star Excursion Balance Test (SEBT) as a measurement method and demonstrated that, compared with healthy individuals, male and female patients with CLBP have deficits in dynamic postural control. In addition, Hooper et al. (2016) noted that relative to healthy participants, participants who had recovered from low back pain continued to exhibit significantly unsatisfactory dynamic postural control. This suggests that CLBP non-athlete patients have dynamic postural control deficits that may be permanent. However, other studies on back pain in young athletes have presented different results. Appiah-Dwomoh et al. (2016) studied back pain in young athletes and discovered that they exhibited no back pain-induced reductions in dynamic postural control. They suggested that this absence may be due to the athletes' use of an alternative methods by which to manage their pain. They surmised that athletes focus on sensory clues provided by the body and produce fine movements based on the effects of back pain on postural control. Thus, they concluded that back pain does not affect the postural control of athletes. However, these authors failed to differentiate between acute or overuse in patients with chronic LBP. Young athletes may have non-chronic back pain or have a shorter CLBP history and less severe overuse CLBP compared to older athletes with a longer training history who have CLBP. In addition, previous studies have not recruited athletes whose sports require massive amounts of repetitive striking with equipment (particularly low handicap golfers with CLBP) who also endure repetitive high load impact during practice. Thus, the overuse striking type of CLBP seen in low handicap golfers may have different levels of risk related to reductions in dynamic postural control as compared to those with acute CLBP and young athletes, which is worth further investigation.

The golf swing comprises two crucial skills: precisely controlling the direction of the golf ball and increasing ball flight distance (Sommer and Rönnqvist, 2009; Sprigings and Neal, 2000; Tinmark et al., 2010). In recent years, in order to achieve better training quality and monitor swing performance and data, athletes and coaches have chosen to use equipment to assist in the training process,

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for example, TrackMan products. The TrackMan portable launch monitor can generate 9 values related to club head impact and 14 values related to the ball flying through Doppler radars and Optically Enhanced Radar Tracking as each swing is performed (Johansson et al., 2015). It is a tool that can be used to assess the accuracy and reliability of golf performance in the form of instant feedback given to players as a training reference. Since it is now common training equipment for elite golfers (PGA, LPGA, and college golf teams), TrackMan can provide information on rapid movement during a golf swing, such as slight differences in the angle and speed of the swing, which is difficult to measure using a high-speed camera, as was the case in the past (Fisher, 2019). Previous studies have noted that the golf swing demands precise motor coordination on the basis of personal physical characteristics. Also, Smith (2010) demonstrated that good golf performance is related to some crucial physiological factors, such as muscular strength, segmental stability, proprioceptive responses, and neurological functioning. However, from the muscle recruitment perspective, the dysfunction of mechanoreceptors in patients with CLBP may cause possible changes in their proprioception, thereby delaying muscle recruitment (Ershad et al., 2009). Also, studies on this topic have reported reduced transverse abdominis endurance in golfers with a history of low back pain during a prone lying task executed on a gym mat (Evans and Oldreive, 2000). Therefore, this raises the question as to whether CLBP may possibly influence golf skills and performance related to precise control of the direction and flight distance of a ball.

Postural control is performed when information from human body systems, including the vestibular, visual and proprioceptive systems, are evaluated and integrated (Winter et al., 1990). The vestibular system provides the body with orientation and acceleration abilities. The visual system provides visual references from the environment, orientation, and tracks the movement of the body. The proprioceptive system provides important information related to body orientation and changes in muscle length, as well as the strength of muscles, joints, and the skin. In addition, the central nervous system decides an appropriate plan for action, and the musculoskeletal system responds in the form of postural control and movements (Winter et al., 1990). To summarize, for well-controlled static and dynamic balance, there should be complex interactions occurring among these systems. Choi et al. (2016) did an experiment, which was a biomechanical evaluation and a test for three targeted groups of subjects (i.e., professional, advanced, and novice groups), making a conclusion that a golf swing requires good dynamic balance control. Using such a test, it has been proven that the peak-to-peak displacement and velocity of the COM and COP of professional golfers are generally lower than those of the advanced and novice player. It is noteworthy that patients with LBP have been found to have higher COP oscillations when performing balance activities in an unstable seated position (Radebold et al., 2001). Numerous methods have been used to assess abilities related to dynamic postural control. The SEBT (the Star Excursion Balance Test) is a common, highly reliable instrument used to assess dynamic postural control, as well as balance and injury risks, among both athletes and the general population (Gibson et al., 2018). It is frequently used for assessment in rehabilitation courses. The SEBT represents the control of dynamic balance in eight directions, where a loss of control may lead to deficits in dynamic postural balance for a number of reasons. By analyzing the ICCs for the eight cardinal directions (Hertel et al., 2000), Hyong and Kim (2014) revealed that the ICCs for the intrarater and interrater reliability of the SEBT range between 0.88 and 0.96 and between 0.83 and 0.93, respectively, thereby indicating high reliability. According to previous studies, a deficit in the anterior reach distance in the SEBT may result from smaller hip flexion and greater knee flexion, and that in posteromedial and posterolateral reach distances may result from the strength of the hip flexion and the strength of the knee flexion and hip extensors (Pinheiro et al., 2019). With the exception of the joint range of motion and strength of the lower limbs, lower back injuries lead to proprioceptive deficits and also affect posterior directional control in the SEBT (Hooper et al., 2016). Previous studies have indicated that the intraclass correlation coefficients (ICCs) for the SEBT range between 0.78 and 0.96. Considering the athletic characteristics of golfers and their high incidence of low back injury, the purposes of this study can be stated as follows: (1) to investigate whether low handicap elite golfers with CLBP will exhibit deficits in dynamic postural control, (2) to explore whether the SEBT is a valid measure to determine return to competition in golfers with CLBP, and (3) to investigate whether CLBP affects golfers in terms of their golf swing parameters. An attempt is made in this study to clarify the influence of golf overuse-induced CLBP in terms of both postural control and swing performance. This study is intended to provide useful information for golf coaches, trainers, and rehabilitation personnel, as well as a simple method by which to assess postural control that will provide a reference for designing training regimens and monitoring the training and recovery of golfers with CLBP.

Methods

Subjects

A summary of the subject demographics related to this study are provided in Table 1. In this study, a total of 15 low handicap golfers were recruited. Nine were healthy participants, who comprised the control group, and six had CLBP, who comprised the experimental CLBP group. The participants in the CLBP group were still suffering from low back pain that had been ongoing for more than six months prior to the study. However, these participants could still undergo training and enter competitions due to the fact that the pain is chronic. These golfers were Division 1 athletes at the university level, and their right hand and leg were dominant.

The exclusion criteria for the CLBP group was an acute injury that made it impossible to perform a golf swing. The inclusion criteria in this study were in line with the criteria proposed by Ganesh et al. (2015) and were assessed by a licensed doctor. Only six golfers with CLBP met the criteria, which were as follows: (1) pain located in the lower back lasting for more than six months, where the pain is concentrated in the lower back only (meaning that no pain exists in the upper back area or in the lower marginal part of the buttocks), (2) no common conditions causing symptoms associated with chronic low back pain, including sciatica, ankylosing spondylitis, degenerative disk disease, disk herniation, osteoarthritis, spinal stenosis, spondylolisthesis, lumbosacral facet syndrome, failed back surgery syndrome, malignancy, and cauda equina syndrome, (3) no history of sciatica or other radicular pain, (4) a negative neurological examination, (5) no muscle strength decline due to nerve root dysfunction that would lead to declines in muscle strength or bladder and defecation function issues, and (6) no orthopaedic condition related to the hips, knees, ankles, and legs. The participants with CLBP had no complaints of vestibular or neurological diseases during recruitment. The nine healthy golfers in the control group had no history of low-back injuries or injuries to the upper or lower limbs during the six months prior to participation in this study. The scoring for the CLBP group was 3.17 ± 0.90 points, as assessed by the Roland–Morris Disability Questionnaire (RMDQ) (Roland and Fairbank, 2000). The scoring on the RMDQ ranged from 0-24, with higher scores indicating a higher influence of CLBP. The experimenters explained the test content to the participants, and all participants signed an informed consent form. This study was approved by the National Cheng Kung University Committee for Human Research Ethics.

SEBT and golf swing performance

The SEBT setup and procedure were administered according to Gribble and Hertel (2003), as follows: (1) The experimental setup was done in a laboratory. (2) Eight measuring tapes (200 cm) were arranged into a star shape with a 45°angle between any two measuring tapes. (3) The eight directions tested included the anterior (A), anteromedial (AM), medial (M), anterolateral (AL), medial–lateral (ML), posterior (P), posteromedial (PM), and posterolateral (PL) directions. (4) A participant stood in the center of the star shape with one foot, and the other foot extended maximally in each of the eight directions to touch the ground before returning to the center location. During the process, if the participant lost his or her balance and left the center location, the performance was disregarded, and the test was repeated. (5) The tester recorded the participant's touchdown performance. Each of the participants performed the SEBT for both legs. The SEBT was administered to each participant by the same tester to avoid subjective bias. All participants practiced six times in each direction to reduce the influence of a learning effect on the measurement results (Hertel et al., 2002). When performing the SEBT in this study, the test administrator scored the leg that was bearing weight on the floor. In addition, according to the intra-reliability test, the intraclass correlation coefficient (ICC) revealed excellent reliability coefficients for the SEBT (0.90-0.93). In this study, the golf swing performance of all participants was analyzed. Each participant first had a 10-min warm up, which included golf swing practice. Subsequently, a 7-iron was used for the 10-repetition swing test to obtain an average value. A TrackMan (TrackMan IIIe, TrackMan Golf, Vedbæk, Denmark) trajectory analyzer was used to collect the data on the performance parameters of the participants' swings (MacKenzie et al., 2015) (Figure 1). According to the requirement of the TrackMan system, 4 meters was set as the distance between thew ball and the target (the big white cloth) inside the room. The procedures for using the TrackMan are as follows: (1) The TrackMan equipment was placed three meters behind the location of the ball. At the same time, one target (the flying direction) was set four meters in front of the ball. (2) TrackMan Performance Studio (TPS) software was connected with the TrackMan equipment through a computer. (3) After the participants warmed up, the swing test was conducted after determining that the TrackMan was available to collect the data. (4) After a total of ten swings, all the data were shown in TPS. These parameters included the club speed, ball carry, attack angle, face angle, launch angle, swing plane, and smash factor.

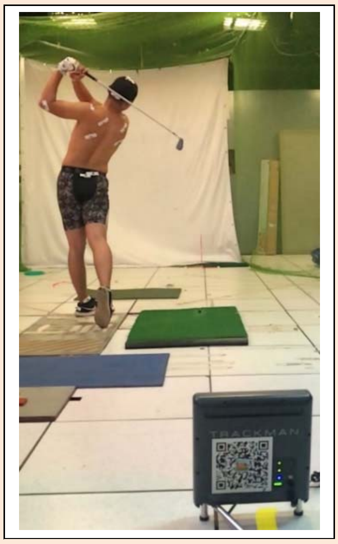

Figure 1. The Doppler radar launch monitor and associated software (TrackMan) utilized for performance of the golf swing.

The TrackMan portable launch monitor provided the seven parameters of interest in this study 1-2 seconds after the golf shots using advanced Doppler radar technology (Fisher, 2019; Johansson et al., 2015). The related definitions of the seven parameters are as follows (Johansson et al., 2015):

Club Speed - Speed of the club head at impact.

Attack Angle - Vertical movement of the club through impact.

Face Angle - Orientation of the club face, relative to target line, at impact.

Launch Angle - Launch angle, relative horizon, immediately after impact.

Length - calculated total, including bounce and roll at zero elevation.

Swing Plane - Bottom half of the swing plane relative to ground.

Smash Factor - Ball speed / club head speed at instant after impact.

Data analysis

The normalization process involved dividing every excursion distance by the leg length of the participant and then multiplying by one hundred. The normalized values were a percentage of the excursion distance related to the participant's leg length. Three specific factors were classified based on the data generated by TrackMan: 1) the output data was speed and distance, which was related to the speed performance (not to the direction), and was classified as the speed/power performance factor. 2) The data related to the direction (related to directional control) was classified as the control/technique factor. 3) The efficiency factor (Smash Factor) was defined as the amount of energy transferred from the club head to the golf ball and was equal to the ball speed divided by the club head speed. SPSS 18.0 software was used to analyze the SEBT results and the swing performance data. An independent-sample t-test was performed to analyze the SEBT results and the swing data. The significance level (α) was set to 0.05.

Results

The participants did not differ in age, height, or mass (Table 1). The score of the CLBP group on the RMDQ ranged from 3.17 ± 0.90 points. According to competition performance data six months prior to the study, the average handicap levels for the CLBP and control groups were +2.83 ± 2.27 and +2.44 ± 1.95, respectively, indicating no between-group differences (p = 0.747) regarding their level of technique. Long-term skill training and current training status (skill training level and physical training level) may lead to overuse of the body. However, the two groups did not differ with respect to the number of years of training (9.50 ± 1.98 years for the CLBP group; 9.89 ± 1.97 years for the control group) (p = 0.733). As for the training-related workload, the CLBP and control groups received skill training for 29.33 ± 7.45 hours and 27.22 ± 7.02 hours weekly, respectively (p = 0.613). In addition, the CLBP and control groups received physical training for 4.25 ± 1.07 hours and 4.08 ± 2.14 hours weekly, respectively (p = 0.872). No between-group differences were observed with respect to total numbers of hours for 1) skill training (p = 0.613) and 2) physical training (p = 0.457). The SEBT and swing performance results are presented in Tables 2 and 3, respectively. Low handicap golfers were analyzed to determine whether having CLBP would affect their dynamic postural control and golf swing performance. The results indicated that the participants having CLBP had lower scores for SEBT (both feet in the M, L, P, PM, and PL directions) ($p < 0.05$) because of unsatisfactory control of dynamic posture. However, the CLBP group obtained a higher SEBT score for the right foot (the back foot for swing direction) in the AL direction (p = 0.012).

For the speed/power performance factor, the club speed (p = 0.046) and ball carry (p = 0.009) parameters for the CLBP group were lower than those for the control group. For the control/technique factor, the CLBP group exhibited a more upright swing plane (p = 0.021). In terms of the impact moment, the two groups did not differ with respect to the attack angle (p = 0.104) and face angle (p = 0.498) of the club head or the launch angle (p = 0.978) of the ball. The ratio of the club speed to ball speed was used to represent swing efficiency. No between-group differences were found for the smash factor (p = 0.826).

Discussion

The results of this study diverge from those of Appiah-Dwomoh et al. (2016), who found that young athletes with back pain, being more aware of their body and the sensation of pain, performed more fine movements to compensate for the influence of back pain on postural control. It is possible that back pain is less likely to influence young athletes' postural control ability, where athletes' low SEBT scores may be attributed to the impact of back pain. In our study, golfers with CLBP obtained lower SEBT scores likely because they, as highly-skilled golfers, engaged in long periods of skill training (29 hours of training weekly). Notably, previous studies have indicated that is it likely that golfers experience low back injury due to repeated golf swings, resulting in low-back overuse (McCarroll, 2001). The major reason appears to be the higher levels of trunk muscle activity during the performance of the golf swing. This may be deleterious to the structures of the lower back (Cole and Grimshaw, 2016). Low back injuries have been attributed to the repeated golf swing movement, resulting in overuse of the lower back (McCarroll, 2001). Among the athletes in the present study, the average number of years of training was 9.50 ± 1.98 and 9.89 ± 1.97 years for the CLBP and control group, respectively.

Table 1. General characteristics of the golfers. (n = 15). Data are means (±SD).

Group	CLBP (n = 6)	Control (n = 9)	*P* value
Age (years)	21.33 ±0.75	22.78 ± 2.70	0.487
Height (m)	1.77 ± 0.04	1.75 ± 0.03	0.422
Mass (kg)	72.50 ± 11.12	73.78 ± 4.71	0.780
RMDQ (scale 0-24)	3.17 ± 0.90	NA	NA
Handicap	2.83 ± 2.27	2.44 ± 1.95	0.747
Training years (years)	9.50 ± 1.98	9.89 ± 1.97	0.733
Skill training per week (days)	5.50 ± 0.50	5.44 ± 0.83	0.893
Skill training per day (hours)	5.33 ± 1.37	5.00 ± 0.94	0.613
Skill training total amount (hours/week)	29.33 ± 7.45	27.22 ± 7.02	0.613
Physical training per week (days)	2.58 ± 0.73	2.72 ± 1.34	0.832
Physical training per day (hours)	1.67 ± 0.24	1.50 ± 0.46	0.457
Physical training total amount (hours/week)	4.25 ± 1.07	4.08 ± 2.14	0.872

SD = standard deviation; CLBP=chronic low back pain; RMDQ =Roland Morris Disability Questionnaire.

Table 2. Normalized reach distance (% limb length) on the Star Excursion Balance Test for each limb. Normalized Reach Distance on the Star Excursion Balance Test for Each Limb. Data are means (±SD).

	Direction	CLBP	Control	*P* value	Effect size
Left foot	AL	77.77 ± 5.29	73.10 ± 5.470	0.125	0.87
	A	87.91 ± 4.04	86.05 ± 4.78	0.448	0.42
	AM	92.33 ± 4.68	95.44 ± 5.52	0.277	0.61
	M	95.47 ± 5.17	103.58 ± 6.54	0.024*	1.38
	PM	98.26 ± 6.70	111.83 ± 7.98	0.005**	1.84
	P	100.70 ± 5.25	113.19 ± 5.00	0.000**	2.44
	PL	92.60 ± 7.93	105.83 ± 5.44	0.002**	1.95
	L	79.60 ± 6.77	92.05 ± 7.19	0.005**	1.78
Right foot	AL	77.75 ± 4.82	69.15 ± 6.03	0.012**	1.58
	A	87.60 ± 4.59	84.31 ± 3.38	0.132	0.82
	AM	93.52 ± 3.11	95.59 ± 5.73	0.437	0.45
	M	95.45 ± 7.28	103.72 ± 6.41	0.037*	1.21
	PM	97.37 ± 6.06	110.39 ± 8.89	0.008**	1.71
	P	98.57 ± 9.40	112.09 ± 6.81	0.006**	1.65
	PL	92.45 ± 7.62	104.80 ± 5.32	0.003**	1.88
	L	81.57 ± 9.10	91.24 ± 7.61	0.044*	1.15

AL = anterolateral; A = anterior; AM= anteromedial; M= medial; PM= posteromedial; P = posterior; PL = posterolateral; L = lateral; * $p < 0.05$, ** $p < 0.01$

Table 3. Swing performance descriptive statistics. Data are means (±SD).

Swing variable	CLBP	Control	*P* value	Effect size
CS	84.12 ± 8.20	91.91 ± 5.57	0.046*	1.11
AA	-2.40 ± 2.07	-4.05 ± 1.58	0.104	0.90
FA	-0.95 ± 3.84	0.29 ± 3.01	0.498	0.36
LA	18.72 ± 2.91	18.68 ± 1.81	0.978	0.02
L	157.53 ± 7.29	168.92 ± 6.82	0.009*	1.61
SP	56.92 ± 3.41	53.08 ± 2.30	0.021*	1.32
SF	1.35 ± 0.09	1.34 ± 0.06	0.826	0.13

CS= club speed (mph); AA= attack angle (deg); FA= face angle (deg); LA= launch angle (deg); L= length (yds); SP= Swing plane (deg); SF = Smash factor. * $p < 0.05$, ** $p < 0.01$.

Because of the long-term use of equipment and repeated exposure to high-intensity impact, swing movement may have had a long-term influence on the lower back in these athletes, further affecting their postural control. In addition, Ganesh et al. (2015) conducted the SEBT on non-athletes who had experienced CLBP for more than six months. Their research results showed that, with the exception of the posterior direction, where no difference was found between the CLBP and healthy groups, in the other seven directions, the CLBP group obtained lower SEBT scores than the healthy group. These results indicated that without visual and vestibular dysfunction, the unsatisfactory dynamic postural control of the CLBP group may have been due to a reduction in proprioceptive feedback from mechanoreceptors. Nevertheless, in addition to exposure to long-term high-intensity impact from equipment, golfers with CLBP may receive reduced proprioceptive feedback, thereby resulting in a deficit in dynamic postural control in the M, L, P, PM, and PL directions. However, probably because golfers receive support from lower-limb muscle strength and because of their physical training, the two groups did not differ with respect to SEBT performance in the A and AM directions, where the visual system can provide feedback. Intriguingly, it was discovered that the CLBP group exhibited high SEBT scores on the right lateral side of their back foot in the AL direction. We attributed this 1) to the swing movement being in a unilateral movement mode and 2) to the right foot mainly functioning to support the spin action for a golf swing and to reduce displacement. To compensate for dynamic balance deficits in other directions, golfers with CLBP may engage in compensatory movement to maintain their original swing performance and skill level. Lindsay and Horton (2002) revealed that among excellent golfers, those with low back pain, at a fixed swing speed and relative to their healthy counterparts, exhibited excessive body rotation and a dynamic X-factor. This phenomenon probably explains why the CLBP group obtained a higher SEBT score for their right foot in the AL direction-to compensate for the deficit due to CLBP. It was also found that compared with the control group, the CLBP group exhibited a more unsatisfactory club speed and ball carry when using a 7-iron. In future applications, it can be investigated (1) whether decreases in club speed and ball carry distance can be monitored and controlled and (2) whether SEBT performance declines in the M, L, P, PM, and PL directions. The results of these future investigations could serve as an indicator as to whether golfers with CLBP have recovered completely.

The two essential skills for a golf swing are precise control of the ball direction and increasing the ball flying distance (Sommer and Rönnqvist, 2009; Sprigings and Neal, 2000; Tinmark et al., 2010). Notably, ball carry depends on a golfer's swing speed. In the present study, the CLBP group had experienced back pain for more than six months. It was discovered in the present study that the CLBP group exhibited more unsatisfactory performance with respect to club speed and ball carry than the control group did. Evans and Oldreive (2000) indicated that in golfers with low back pain, the muscular endurance of their transverse abdominal muscle is significantly reduced. In addition, Hooper et al. (2016) demonstrated that unsatisfactory postural control in athletes with CLBP is correlated with lumbar extension strength. Relevant studies have indicated that CLBP can result in a decline in torso muscle strength and muscular endurance, which potentially explains the slow swing speed and short ball flying distance. It was observed in the present study that the CLBP group exhibited unsatisfactory dynamic balance as compared to the control group. Considering postural control and power, one previous study indicated that unstable body postural control substantially reduces strength, power, and movement speed (Granacher and Gollhofer, 2012). The findings of that study offer another perspective explaining why golfers with CLBP exhibit unsatisfactory swing performance. Also, in the present study, the swing plane angle for the CLBP group was greater than that for the healthy group. With no between-group differences in mass and skill level, the participants in the CLBP group tended to adopt an upright swing plane. This may be a compensatory movement made by those in the CLBP group to reduce the pressure on their lower back. Gluck et al. (2008) indicated that adopting an upright stance can reduce low back pressure. With respect to a technical analysis, stance adjustment directly influences the swing plane. In terms of their swing movement, golfers in the CLBP group likely made technical adjustments to cope with their low back pain in the short term or to reduce the burden on their lower back in the long-term. Nevertheless, with no between-group differences found in the numerical attack angle, face angle, and launch angle values in terms of either control or technique, adopting an upright swing plane was the main technical characteristic of golfers with CLBP.

This study has some limitations. First, the method used to assess CLBP in this study, as proposed by Ganesh et al. (2015), could not accurately identify the degree of injury that was causing the low back pain in the participants. In addition, only low-handicap, highly-skilled golfers were considered in the present study. Thus, our findings may not be applicable to less skilled (e.g., novice) golfers. Furthermore, our sample size was relatively small, which may have impacted the power of the results. However, it is difficult to recruit participants with CLBP who can still take part in their regular training. As a result, after golfers with acute waist pain and those who could not swing a golf club were excluded, the remaining number of participants was limited. Finally, CLBP can stem from various causes; thus, generalizing conclusions should be done with caution.

Conclusion

It was discovered in the current study that having CLBP results in more unsatisfactory SEBT performance for both feet in the M, L, P, PM, and PL directions but good performance for the back foot in the AL direction due to the ability of the golfers to compensate for the influence of CLBP. With regard to swing performance, the CLBP group exhibited unsatisfactory club speed and ball carry. In addition, the CLBP group tended to exhibit a more upright swing plane. Golfers are especially prone to low back pain, and CLBP clearly affected the SEBT pattern and swing characteristics of the participants in this study. The SEBT is a low-cost, convenient, easily implemented measure suitable for assessing golf training and recovery from injuries. Long-term individualized monitoring and control of golfers' dynamic postural control may provide information that will facilitate both training and injury assessment. Furthermore, long-term collection of swing data (especially swing plane, club speed, and ball carry) may aid the health management of golfers and the assessment of their athletic performance.

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References

Appiah-Dwomoh, E., Müller, S., Hadzic, M. and Mayer, F. (2016) Star Excursion Balance Test in young athletes with back pain. *Sports* **4,** 44. https://doi.org/10.3390/sports4030044

Bogduk, N. (2004) Management of chronic low back pain. *Medical Journal of Australia* **180,** 79-83. https://doi.org/10.5694/j.1326-5377.2004.tb05805.x

Brumagne, S., Cordo, P., Lysens, R., Verschueren, S. and Swinnen, S. (2000) The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine* **25,** 989-994. position sense in individuals with and without low back pain. Spine 25, 989-994. https://doi.org/10.1097/00007632-200004150-00015

Choi, A., Sim, T. and Mun, J.H. (2016) Improved determination of dynamic balance using the centre of mass and centre of pressure inclination variables in a complete golf swing cycle. *Journal of Sports Sciences* **34,** 906-914. https://doi.org/10.1080/02640414.2015.1076572

Cole, M.H. and Grimshaw, P.N. (2016) The biomechanics of the modern golf swing: implications for lower back injuries. *Sports Medicine* **46,** 339-351. https://doi.org/10.1007/s40279-015-0429-1

Ershad, N., Kahrizi, S., Abadi, M.F. and Zadeh, S.F. (2009) Evaluation of trunk muscle activity in chronic low back pain patients and healthy individuals during holding loads. *Journal of Back and Musculoskeletal Rehabilitation* **22,** 165-172. https://doi.org/10.3233/BMR-2009-0230

Evans, C. and Oldreive, W. (2000) A study to investigate whether golfers with a history of low back pain show a reduced endurance of transversus abdominis. *Journal of Manual & Manipulative Therapy* **8,** 162-174. https://doi.org/10.1179/jmt.2000.8.4.162

Farahbakhsh, F., Rostami, M., Noormohammadpour, P., Mehraki Zade, A., Hassanmirazaei, B., Faghih Jouibari, M., Kordi, R. and Kennedy, D.J. (2018) Prevalence of low back pain among athletes: A systematic review. *Journal of Back and Musculoskeletal Rehabilitation* **31,** 901-916. https://doi.org/10.3233/BMR-170941

Fisher, K. (2019) A Repeated-Measures Assessment of Golf Shot Performance at Varying Distances in Collegiate Female Golfers using the Trackman Portable Launch Monitor. *Journal of Advanced Sport Technology* **3,** 1-7.

Fradkin, A.J., Finch, C.F. and Sherman, C. (2003) Warm-up attitudes and behaviours of amateur golfers. *Journal of Science and Medicine in Sport* **6,** 210-215. https://doi.org/10.1016/S1440-2440(03)80256-6

Ganesh, G.S., Chhabra, D. and Mrityunjay, K. (2015) Efficacy of the star excursion balance test in detecting reach deficits in subjects with chronic low back pain. *Physiotherapy Research International* **20,** 9-15. https://doi.org/10.1002/pri.1589

Gibson, A.L., Wagner, D. and Heyward, V. (2018) *Advanced Fitness*

Assessment and Exercise Prescription, 8E. Human kinetics.
Gluck, G.S., Bendo, J.A. and Spivak, J.M. (2008) The lumbar spine and low back pain in golf: a literature review of swing biomechanics and injury prevention. *The Spine Journal* **8,** 778-788. https://doi.org/10.1016/j.spinee.2007.07.388
Gosheger, G., Liem, D., Ludwig, K., Greshake, O. and Winkelmann, W. (2003) Injuries and overuse syndromes in golf. *The American Journal of Sports Medicine* **31,** 438-443. https://doi.org/10.1177/03635465030310031901
Granacher, U. and Gollhofer, A. (2012) Is there an association between variables of postural control and strength in prepubertal children? *The Journal of Strength & Conditioning Research* **26,** 210-216. https://doi.org/10.1519/JSC.0b013e31821b7c30
Gribble, P.A. and Hertel, J. (2003) Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in Physical Education and Exercise Science* **7,** 89-100. https://doi.org/10.1207/S15327841MPEE0702_3
Hertel, J., Gay, M.R. and Denegar, C.R. (2002) Differences in postural control during single-leg stance among healthy individuals with different foot types. *Journal of Athletic Training* **37,** 129-132.
Hertel, J., Miller, S.J. and Denegar, C.R. (2000) Intratester and intertester reliability during the Star Excursion Balance Tests. *Journal of Sport Rehabilitation* **9,** 104-116. https://doi.org/10.1123/jsr.9.2.104
Hooper, T.L., James, C.R., Brismée, J.-M., Rogers, T.J., Gilbert, K.K., Browne, K.L. and Sizer, P.S. (2016) Dynamic balance as measured by the Y-Balance Test is reduced in individuals with low back pain: A cross-sectional comparative study. *Physical Therapy in Sport* **22,** 29-34. https://doi.org/10.1016/j.ptsp.2016.04.006
Hyong, I.H. and Kim, J.H. (2014) Test of intrarater and interrater reliability for the star excursion balance test. *Journal of Physical Therapy Science* **26,** 1139-1141. https://doi.org/10.1589/jpts.26.1139
Johansson, U., König, R., Brattberg, P., Dahlbom, A. and Riveiro, M. (2015). Mining trackman golf data. In: *2015 International Conference on Computational Science and Computational Intelligence (CSCI)*, IEEE, pp. 380-385. https://doi.org/10.1109/CSCI.2015.77
Lindsay, D. and Horton, J. (2002) Comparison of spine motion in elite golfers with and without low back pain. *Journal of Sports Sciences* **20,** 599-605. https://doi.org/10.1080/026404102320183158
MacKenzie, S.J., Ryan, B. and Rice, A. (2015) The influence of clubhead mass on clubhead and golf ball kinematics. *International Journal of Golf Science* **4,** 136-146. https://doi.org/10.1123/ijgs.2015-0011
McCarroll, J.R. (2001) Overuse injuries of the upper extremity in golf. *Clinics in Sports Medicine* **20,** 469-479. https://doi.org/10.1016/S0278-5919(05)70263-5
McCarroll, J.R., Rettig, A.C. and Shelbourne, K.D. (1990) Injuries in the amateur golfer. *The Physician and Sportsmedicine* **18,** 122-126. https://doi.org/10.1080/00913847.1990.11709999
Pinheiro, L.S.P., de Melo Ocarino, J., Bittencourt, N.F.N., Souza, T.R., de Souza Martins, S.C., Bomtempo, R.A.B. and Resende, R.A. (2019) Lower limb kinematics and hip extensors strengths are associated with performance of runners at high risk of injury during the modified Star Excursion Balance Test. *Brazilian Journal of Physical Therapy* **24(6)**, 488-495. https://doi.org/10.1016/j.bjpt.2019.07.011
Radebold, A., Cholewicki, J., Polzhofer, G.K. and Greene, H.S. (2001) Impaired postural control of the lumbar spine is associated with delayed muscle response times in patients with chronic idiopathic low back pain. *Spine* **26,** 724-730. https://doi.org/10.1097/00007632-200104010-00004
Roland, M. and Fairbank, J. (2000) The Roland–Morris disability questionnaire and the Oswestry disability questionnaire. *Spine* **25,** 3115-3124. https://doi.org/10.1097/00007632-200012150-00006
Smith, M.F. (2010) The role of physiology in the development of golf performance. *Sports Medicine* **40,** 635-655. https://doi.org/10.2165/11532920-000000000-00000
Sommer, M. and Rönnqvist, L. (2009) Improved motor-timing: Effects of synchronized metro-nome training on golf shot accuracy. *Journal of Sports Science and Medicine* **8,** 648-656. https://pubmed.ncbi.nlm.nih.gov/24149608
Sprigings, E.J. and Neal, R.J. (2000) An insight into the importance of wrist torque in driving the golfball: a simulation study. *Journal of Applied Biomechanics* **16,** 356-366. https://doi.org/10.1123/jab.16.4.356
Tinmark, F., Hellström, J., Halvorsen, K. and Thorstensson, A. (2010) Elite golfers' kinematic sequence in full-swing and partial-swing shots. *Sports Biomechanics* **9,** 236-244. https://doi.org/10.1080/14763141.2010.535842
Winter, D.A., Patla, A.E. and Frank, J.S. (1990) Assessment of balance control in humans. *Medical Progress Through Technology* **16,** 31-51.

Key points

- Elite golfers with CLBP exhibit poor performance for both feet in the M, L, P, PM, and PL directions but good performance for the back foot in the AL direction and are thus able to compensate for the influence of CLBP.
- Regarding swing performance, the CLBP group exhibited unsatisfactory club speed and ball carry. In addition, this group tended to produce a more upright swing plane.
- Our findings suggest that SEBT may be feasible and highly accessible to assess golf swing performance of elite players with CLBP.

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