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The crunch factor's role in golf-related low back pain

Michael H. Cole, PhD[a,*], Paul N. Grimshaw, PhD[b]

[a]School of Exercise Science, Faculty of Health Sciences, Australian Catholic University, PO Box 456, Virginia, Queensland 4014, Australia
[b]School of Mechanical Engineering, Faculty of Engineering, Computer and Mathematical Sciences, The University of Adelaide, Adelaide, South Australia 5005, Australia

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Abstract

BACKGROUND CONTEXT: The golf swing exposes the spine to complex torsional, compressive, and shearing loads that increase a player's risk of injury. The crunch factor (CF) has been described as a measure to evaluate the risk of low back injuries in golfers and is based on the notion that lateral flexion and axial trunk rotation jointly contribute to spinal degeneration. However, few studies have evaluated the appropriateness of this measure in golfers with low back pain (LBP).

PURPOSE: To objectively examine the usefulness of the CF as a measure for assessing the risk of low back injury in golfers.

STUDY DESIGN: Field-based research using a cross-sectional design.

METHODS: This research used three-dimensional motion analysis to assess the golf swings of 12 golfers with LBP and 15 asymptomatic controls. Three-dimensional kinematics were derived using Vicon Motus, and the CF was calculated as the instantaneous product of axial trunk rotation velocity and lateral trunk flexion angle.

RESULTS: Maximum CFs and their timings were not significantly different between the symptomatic and asymptomatic groups. Furthermore, for those golfers who produced higher CFs (irrespective of the group), the increased magnitude could not be attributed to an increased axial angular trunk velocity or lateral flexion angle, but rather to a concomitant increase in both of these variables.

CONCLUSIONS: The findings suggested that although the fundamental concepts that underpin the CF seem sensible, this measure does not appear to be sensitive enough to distinguish golfers with LBP from the asymptomatic players.

Keywords: Golf swing; Lumbar spine; Trunk motion; Injury prevention; Biomechanics

Introduction

Over the past decade, golf has established itself as one of the most popular sports around the world, largely due to the fact that it poses no restrictions on gender or age and, thus, can be enjoyed late into one's lifetime [1–7]. However, despite the appeal of the game, several researchers have suggested that the increased popularity of golf combined with the common misconception that it is a risk-free sport have effectively increased the prevalence of golf-related injuries [8–11]. Of these injuries, those to the lower back have consistently been reported to be the most common [12,13], with incidences as high as 50% in the amateur and professional golfing populations [14]. According to Hosea and Gatt [15] and Armstrong [16], most cases of golf-related low back pain (LBP) are caused by mechanical damage to the spinal column or the associated structures. Furthermore, research suggests that up to 90% of low back injuries in the professional golfing population arise because of the repeated performance of the modern golf swing [17–23]. During a single practice session, it is not uncommon for golfers to perform this movement sequence for more than 300 times [24–26], and research demonstrates that golfers who have developed LBP tended to have practiced the full golf swing twice as often as their asymptomatic counterparts [27].

The repeated performance of the golf swing exposes the spine to a complex series of high-speed spinal loads, including axial torsional stresses, compression, and shear

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* Corresponding author. School of Exercise Science, Australian Catholic University, PO Box 456, Virginia, Queensland 4014, Australia. Tel.: (61) 7-3623-7674; fax: (61) 7-3623-7650.

E-mail address: michael.cole@acu.edu.au (M.H. Cole)

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forces [8,15,28–32]. Additionally, through the use of X-ray and computed tomography scans, previous research has demonstrated asymmetric degenerative changes in the lumbar facet joints of professional golfers compared with non-golfer controls [33,34]. According to Hosea et al. [21,35] and Lim and Chow [36], peak compression, shear, and torsional forces were achieved during the downswing and follow-through phases of the golf swing. The timing of these loads corresponds with anecdotal evidence, which suggested that up to 41% of low back injuries are sustained during the downswing or at impact, whereas the follow-through phase has been linked to a similar proportion of these injuries [37,38]. The motion of the trunk during the right-handed golf swing has been described as a combination of right-side lateral flexion and counterclockwise axial rotation during the downswing [34]. Both of these factors increase rapidly during the downswing and the early follow through, reaching their maximum shortly after ball impact [34]. Based on this knowledge, Sugaya et al. [39] proposed the use of a unique kinematic variable, dubbed the crunch factor (CF), to objectively measure and compare the mechanics of the lumbar spine in healthy and pathologic golf swings.

The CF was intuitively devised based on the hypothesis that lateral flexion angle and axial trunk rotation both contribute to degenerative changes and injuries in the lumbar spine. This notion has been supported by other researches, which state that the forceful lateral displacement of the hips combined with rapid hip rotation and trunk hyperextension are some of the most prominent causes of LBP in modern golf [34,40–42]. Despite this link, Gluck et al. [43] suggest that the clinical relevance of the CF is controversial because of the lack of empirical evidence to support its use. To date, the authors are only aware of two studies that have reported calculating the CF in a population of golfers with LBP [27,44]. In contrast to the original work of Sugaya et al. [39], which calculated the CF for the lumbar spine only, Lindsay and Horton [27] computed a trunk CF that also included the motion of the thoracic spine. According to Lindsay and Horton [27], the symptomatic golfers produced lower peak trunk CF values than asymptomatic controls (although not significantly so), but their findings were based on a small sample of six golfers with and without LBP. Furthermore, while Tsai et al. [44] describe calculating the CF for golfers with LBP, the authors did not present the data in the final manuscript. As such, there is a clear need to better understand the possible role of the CF in golf-related low back injuries because this measure has also been suggested to play an important role in low back injuries in fast bowling cricketers [45].

Hence, this research adopted a cross-sectional design to assess whether golfers with LBP demonstrate greater peak CF values than asymptomatic players. This information could provide insight into the possible injury mechanisms associated with the development of golf-related LBP, together with providing some important evidence for the value of the CF as a measure in other similar dynamic contact and impact-related sports.

Methods

Participants

For the purposes of this study, golfers were recruited via advertisements placed in the local newspaper on the notice boards of public and private golf courses located in close proximity to the site of data collection. Interested participants were encouraged to contact the principal investigator and were screened over the phone to ensure that they were older than 18 years, had been playing golf for at least 12 months, and had a current playing handicap. During this process, participants were also asked about any previous or current injuries that affected their participation and were then excluded if they were suffering from any injury other than LBP. Twelve right-handed male golfers who reported experiencing LBP while playing or practicing golf were accepted into the study and asked to complete the Short-Form McGill Pain Questionnaire (SF-MPQ) after their warm-up on the day of testing to establish the severity of their condition [46]. The SF-MPQ incorporates a visual analog scale (100 mm line) that patients use to rank the intensity of their pain, with ‘‘no pain’’ denoted by a score of 0 and ‘‘worst possible pain’’ represented by a score of 100 [46]. Logically constructed from the Long-Form McGill Pain Questionnaire [46], the SF-MPQ has exhibited test-retest reliability, content validity, construct validity, concurrent criterion validity, and predictive validity within the literature, thus supporting its use in the assessment of clinical pain [46–49]. On the basis of this assessment, all golfers reported a mild or greater level of pain on the visual analog scale (mean, 38±14 mm; range, 22–62 mm) and, on average, they described their present pain intensity as discomforting (mean, 2.08±0.67; range, 1–3). A further 15 right-handed male golfers responded to the advertisements and reported no current injuries, no history of spinal surgery, spinal fracture, or spinal deformity, and had not experienced any episodes of LBP requiring medical attention in the previous 12 months. These golfers were recruited to form the no low back pain (NLBP) group (Table 1). All participants provided written informed consent to participate in the investigation, and the experimental methodology was approved by the Human Research Ethics Committee at the university.

Task

Before data collection, the participants were encouraged to partake in their normal warm-up routines that included stretching and/or the performance of several practice strokes using an iron golf club. While this routine allowed the golfers to prepare for the task as they would in a normal game of golf, it also served to familiarize the golfers with the experimental surroundings. After their warm-up, the

Table 1
The average age, height, mass, BMI, and handicap of the LBP and NLBP golfer groups

	LBP golfers (n=12 golfers)					NLBP golfers (n=15 golfers)				
Statistic	Age (y)	Height (m)	Mass (kg)	BMI (kg/m^2)	Handicap	Age (y)	Height (m)	Mass (kg)	BMI (kg/m^2)	Handicap
Mean	46.00	1.85*	84.00	24.77	10.50	39.60	1.77*	82.73	26.48	10.40
SEM	5.15	0.03	1.52	0.71	2.43	3.60	0.01	1.49	0.64	1.07

BMI, body mass index; LBP, low back pain; NLBP, no low back pain; SEM, standard error of the mean.
* Significant difference ($p<.05$) between the groups.

golfers used their own driver (1-wood) and ‘‘natural’’ technique to perform 20 tee-shots in the direction of a flag positioned 320 m away. During the assessment, the participants positioned themselves and the ball approximately in the center of a 2 m^2 area (tee-off box) that was clearly defined on the grass with custom-made markers. To ensure that the golfers could perform the task in an uninhibited manner, all data collection for this research was conducted on a designated grassed area at a local practice driving range.

Data collection

All golfers were asked to wear a singlet and short-length trousers to facilitate the identification (via palpation) of specific anatomical landmarks to serve as reference points during the three-dimensional analysis. Two markers made from reflective adhesive tape were placed on the lateral aspect of the participants’ shoes, overlying the fifth metatarsophalangeal joint. Reflective joint markers were also positioned bilaterally over the lateral malleolus of the fibula, lateral condyle of the femur, greater trochanter, temporomandibular joint, lateral border of the acromion, lateral condyle of the humerus, and the ulnar styloid. A further two markers made from reflective tape were adhered to the shaft of the golf club, one just below the grip and one on the head of the driver. To facilitate the reconstruction of the three-dimensional digitized coordinates, a calibration frame measuring 2.2 m $\times$1.9 m $\times$1.6 m (Peak Performance Technologies, Inc., Englewood, CO, USA) comprising 24 points of known three-dimensional spatial locations (x, y, and z) was filmed in the tee-off box before testing.

Three genlocked Panasonic cameras (Matsushita Electric Industrial Company Ltd., Japan) captured each participant’s performance of the tee-shot at an effective sampling rate of 50 Hz and with a shutter speed of 1/2000 of a second. Although 50 Hz sampling frequency may be considered insufficient to examine high-speed movements such as the golf swing, it is important to consider that this investigation aimed to evaluate patterns of movement rather than high frequency components, such as impact. Similar methods have been used by previous researchers (eg, [50,51]) to assess patterns of motion in golf and, as such, the use of this equipment was considered to be adequate to meet the requirements of the investigation. Each of the three cameras were positioned at a vertical height of 1.25 m (measured from the camera lens) and at a horizontal distance of 5.63 m from the center of the tee-off box. The configuration of the video cameras is depicted in Fig. 1 and is comparable with three-dimensional motion analysis approaches used previously to assess the golf swing [50].

Data analysis

The joint markers for the best three swings for each golfer were digitized using Vicon Motus 9.2.2 (Vicon, Oxford, UK) and three-dimensional kinematic data were derived using the direct linear transformation algorithm [52]. The three best trials were identified by the principal researcher and were based on a qualitative assessment of the shot’s accuracy and flight path after ball contact. A quintic spline function [53] was used to smooth the raw data after coordinate digitisation and data reconstruction, which facilitated the calculation of kinematic quantities. The selection of a spline function was based on the work of Woltring [53] and Challis and Kerwin [54], who suggested that spline functions were more appropriate for processing kinematic data because they accurately replicate the smooth nature of human movement, while eliminating random noise. Sugaya et al. [39] defined the lumbar CF as the instantaneous product of axial angular velocity of the trunk ($\omega_{trunk\ axial}$) and the lateral flexion angle of the spine ($\theta_{trunk\ flexion}$). [Equation 1]

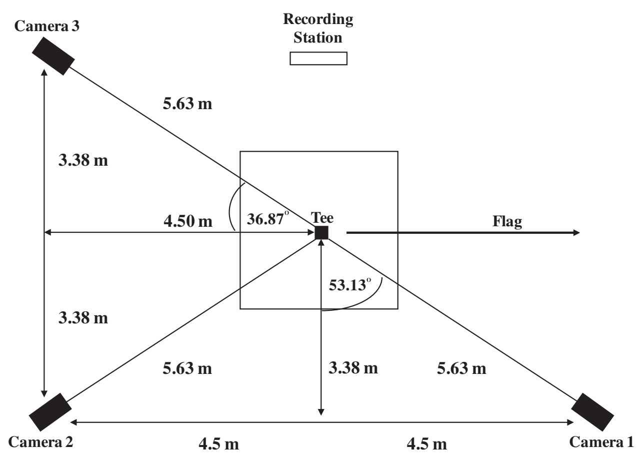

Fig. 1. The layout of the three-dimensional motion analysis equipment.

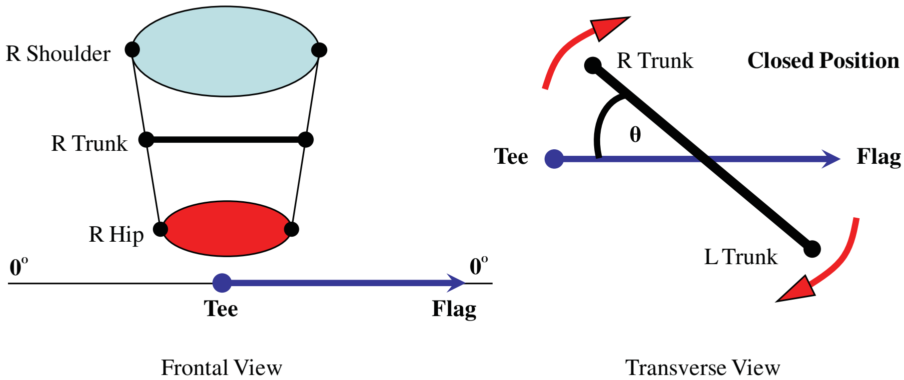

Fig. 2. The defined trunk segment and the resulting trunk angle as viewed from the oblique frontal and transverse planes.

$$CF\left(deg^2/s\right) = \omega_{trunk\ axial}\left(deg/s\right) \times \theta_{trunk\ flexion}\left(deg\right) \quad \text{Equation 1}$$

In the original work by Sugaya et al. [39], the CF was calculated by the multiplication of these variables because they each clearly represented a particular potential injurious component that is present around impact. However, the authors felt that it may be important to point out that the determination of the CF by this method does not appear to have any other rationale and does not seem to have been proposed based on any well-researched criteria. For the purposes of this study, the axial angular trunk velocity was calculated as the change in hip to trunk differential angle over a designated time increment. The hip angle was considered to be the angle formed between the line joining the hip joint centers and a theoretical line parallel to the y-axis between the tee and the target (transverse plane). Similarly, the trunk angle was calculated as the angle formed between this theoretical line and the line between two virtual markers located bilaterally midway between the hip and the shoulder joint markers (Fig. 2). For both the hip and trunk angles, a positive value was indicative of rotation from the neutral position away from the target (closed position; clockwise rotation), whereas rotation from the neutral position toward the target (open position; counter-clockwise rotation) was represented by a negative value. The lateral flexion angle of the spine required two virtual points to be calculated based on the location of the hip and shoulder markers. The mid-hip virtual point was calculated as the half distance between the left and right hip markers, while the mid-shoulder virtual point was calculated in a similar fashion for the left and right shoulder markers. The lateral flexion angle of the spine was subsequently calculated as the angle formed between the line that joined the mid-hip and -shoulder points and the right and left hip markers minus 90° (Fig. 3). A positive lateral trunk flexion angle represented lateral flexion towards the lead hip (left-side lateral bend for a right-handed golfer), while a negative value was indicative of lateral flexion towards the trail hip (right-side lateral bend for a right-handed golfer).

Statistical analysis

To assess for any differences between the two groups with respect to the peak CF and the kinematic variables that constituted this measure, a one-way analysis of variance was conducted using PASW Statistics v18.0 (SPSS Inc., Quarry Bay, Hong Kong). To account for the small sample sizes of the groups, a conservative level of significance was used ($p \leq .01$). Additionally, Cohen's d effect sizes were calculated to provide an insight into the degree to which the independent (IVs) and dependent variables (DVs) were related [55]. In accordance with the tentative recommendations of Cohen [55], an effect size of less than 0.2 was considered to be a negligible effect, whereas an effect size of between 0.2 and 0.5 was classified as small. Similarly, effect sizes between 0.5 and 0.8 were deemed to be indicative of a medium effect, whereas a value greater than 0.8 was representative of a large effect size. Effect sizes assess the degree of association that exists between the IVs and DVs and determine what proportion of the total variance in the DVs (eg, maximum CF) can be estimated by knowledge of the levels of the IVs [56].

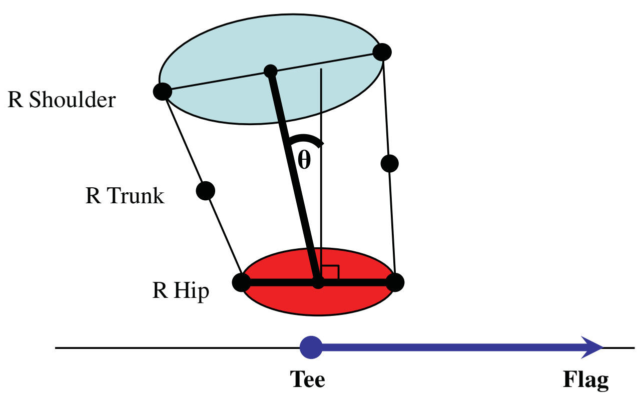

Fig. 3. The method of calculation for the lateral flexion angle of the trunk.

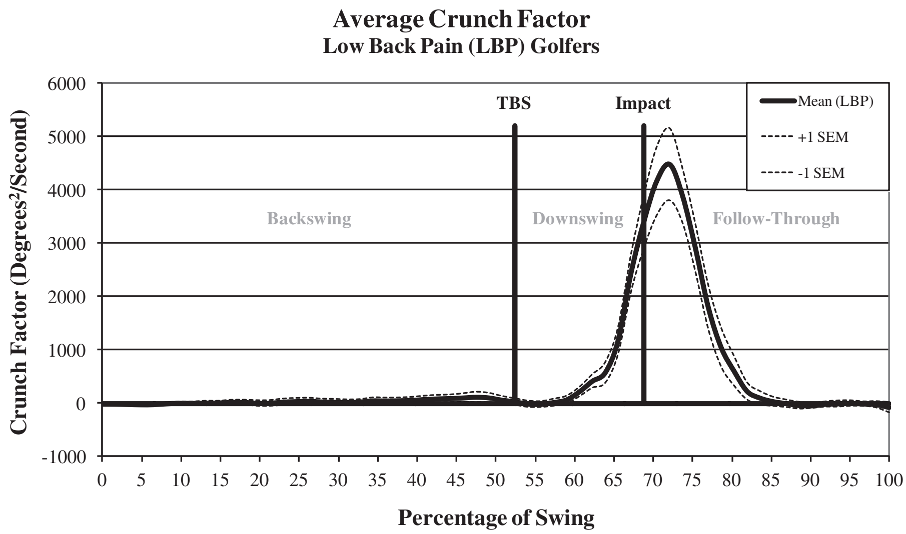

Fig. 4. The mean (±1 SEM) crunch factor recorded throughout the swing for the LBP golfers. The event lines on the graph identify the top of the backswing and the point of impact between the ball and club head. LBP, low back pain; SEM, standard error of the mean; TBS, top of the backswing.

Results

The average CF graphs for the LBP (Fig. 4) and NLBP groups (Fig. 5) illustrate a marked increase in this variable from the midpoint of the downswing through impact and into the early follow through. The average (±standard error of the mean) peak CF value for the LBP golfers (4,879.7±633.6 deg^2/s) was not significantly different to the mean value observed for the NLBP (4,920.2±587.0 deg^2/s) group ($p=.96$; $d=0.02$). Interestingly, for those golfers who produced higher CF values (irrespective of group), the increased magnitude could not be attributed entirely to an increased axial angular trunk velocity or lateral flexion angle, but rather to a concomitant increase in both of these variables. The results of the one-way analysis of variance demonstrated that the timing of peak CF was not significantly different for the LBP (14.4% into the follow-through) and NLBP (12.1% into the follow-through) golfers ($p=.16$; $d=0.55$).

With respect to the lateral flexion angle and the axial angular trunk velocity (Table 2), the results of the statistical analysis showed no significant differences between the LBP and NLBP golfers at address, top of the backswing, impact, or at the time that maximum CF occurred. Similarly, the LBP and NLBP golfers demonstrated very similar patterns of hip and trunk rotation throughout the golf swing (Table 2). However, although not statistically significant

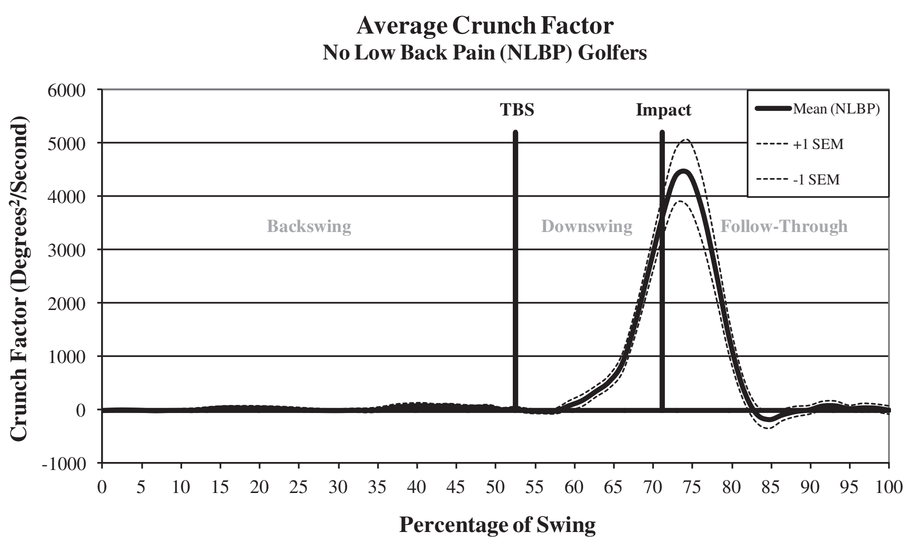

Fig. 5. The average (±1 SEM) crunch factor recorded for the NLBP golfers during the golf swing. The plotted event lines denote the top of the backswing and the point of impact between the ball and club head. NLBP, no low back pain; SEM, standard error of the mean; TBS, top of the backswing.

Table 2
The mean (and SEM) angular trunk kinematics measured for the LBP and NLBP golfers at address, at the TBS, at impact, and at the time that peak CF was achieved

	LBP golfers				NLBP golfers			
Outcome measure	Address	TBS	Impact	At peak CF	Address	TBS	Impact	At peak CF
Lateral trunk flexion (deg)								
Mean	−2.2	1.4	−18.2	−18.1	−1.3	3.5	−16.8	−18.5
SEM	0.6	1.7	1.7	1.5	1.0	1.0	1.4	1.5
Trunk angle (deg)								
Mean	−3.2	58.7	−20.4	−43.9	−5.6	64.5	−20.8	−40.2
SEM	1.2	3.2	2.2	3.7	0.7	2.0	2.4	3.3
Hip angle (deg)								
Mean	−0.7	33.8	−28.6	−40.7	−2.0	35.5	−29.1	−39.1
SEM	1.1	2.5	2.8	3.6	0.8	3.0	3.2	3.5
Hip to trunk separation angle (deg)								
Mean	−2.5	24.8	8.1	−3.2	−3.6	29.0	8.3	−1.1
SEM	0.6	1.2	1.2	1.1	0.7	1.7	1.3	1.4
Axial angular trunk velocity (deg/s)								
Mean	5.3	11.2	−183.4	−266.4	5.7	11.5	−209.0	−256.8
SEM	1.3	6.7	20.5	21.9	1.9	8.0	11.5	13.5
CF (deg^2/s)								
Mean	−12.4	30.3	3,412.3	4,879.7	−7.5	20.1	3,601.2	4,920.2
SEM	5.7	51.8	477.2	633.6	9.0	39.0	362.2	587.0

SEM, standard error of the mean; LBP, low back pain; NLBP, no low back pain; TBS, top of the backswing; CF, crunch factor.

(Table 3), the results of this investigation tended to suggest that the NLBP golfers achieved a greater hip to trunk separation angle at top of the backswing compared with the LBP group (p=.07; d=0.77).

Discussion and implications

Although it has been suggested that the magnitudes of the lateral trunk flexion angle and axial rotational trunk velocity may play a significant role in vertebral degeneration and spinal injuries in golfers, this research demonstrated that both of these variables and the subsequent CF did not differ significantly between golfers with and without LBP. Similar findings were reported previously by Lindsay and Horton [27], who described no significant differences in the peak CF of six symptomatic professional golfers and six asymptomatic controls. The magnitude of the average peak CF values (±1 standard deviation) reported by Lindsay and Horton [27] for their symptomatic (4,720.2±1,253.9 deg^2/s) and asymptomatic golfers (5,026.3±1,627.6 deg^2/s) were similar to the findings presented for this study (LBP=4,879.7±633.6 deg^2/s; NLBP=4,920.2±587.0 deg^2/s). However, the findings of the present study tended to be greater than those presented by Morgan et al. [57] for a group of healthy collegiate (2,586±1,245 deg^2/s), recreational (1,519±986 deg^2/s), and senior golfers (1,270±935 deg^2/s).

With respect to the two kinematic components that comprise the CF, it was interesting to note that the mean peak lateral flexion angles for the LBP (−19.1±5.6°) and NLBP golfers (−19.1±5.7°) were comparable with those presented by Morgan et al. [57] for their three population groups. However, the data presented by Lindsay and Horton [27] showed peak right-side flexion angles that were more than 50% greater than those reported by Morgan et al. [57] and those presented in the present investigation. A possible explanation for this discrepancy is the difference in methodologies used because Morgan et al. [57] and the present investigation both used three-dimensional motion analysis to assess trunk motion, whereas Lindsay and Horton [27] used a triaxial electrogoniometer (lumbar motion monitor). In contrast to these results, the average maximum axial angular velocities of the trunk for the LBP (−271.0±76.8 deg/s) and NLBP groups (−260.4±50.3 deg/s) in the present study tended to be higher than those reported by Morgan et al. [57] and Lindsay and Horton [27]. In their study, Morgan et al. [57] reported peak axial angular trunk velocities of 202 (±19), 143 (±44), and 114 (±50) deg/s for their college, adult, and senior golfing groups, whereas Lindsay and Horton [27] recorded maximum values of 186.1 (±33.4) and 182.4 (±92.6) deg/s for their symptomatic and asymptomatic golfers, respectively.

The lack of a significant finding between the two groups in the present study is important, as it has previously and recently been postulated that axial trunk rotational velocity and lateral flexion angle of the spine may be important in the development of low back injuries [14,34,45,57]. However, although the CF does not appear to be a sensitive measure for distinguishing golfers with LBP from asymptomatic players, the complex movement pattern that it

Table 3
The results of the statistical analysis (p and d values) of the trunk kinematics recorded for the LBP and NLBP golfers during the different phases of the golf swing

Statistical results and effect size estimates												
	Lateral trunk flexion		Trunk angle		Hip angle		Hip to trunk separation		Axial angular trunk velocity		CF	
Phase of swing	p	d	p	d	p	d	p	d	p	d	p	d
Address	.50	0.27	.08	0.74	.32	0.41	.24	0.48	.87	0.07	.67	0.17
TBS	.28	0.44	.12	0.65	.68	0.17	.07	0.77	.98	0.01	.87	0.06
Impact	.51	0.27	.92	0.04	.91	0.05	.93	0.04	.26	0.46	.75	0.12
At peak CF	.86	0.07	.46	0.31	.75	0.13	.27	0.45	.70	0.16	.96	0.02

LBP, low back pain; NLBP, no low back pain; d, Cohen's d effect size; CF, crunch factor; TBS, top of the backswing.

represents may be a contributory factor to overuse injuries. Firstly, it is interesting to note that the occurrence of peak CF values during the early stages of the follow-through coincides with the peak anteroposterior and lateral bending forces presented in previous research [35]. When we consider that the golf swing puts considerable stress on the intervertebral discs that are poorly designed to attenuate shear forces [15,58,59] and that golfers with LBP have altered trunk muscle activity patterns [60,61], it may be reasonable to suggest that golfers with LBP have a reduced capacity to cope with the demands of the movement.

Nonetheless, it is important to consider that a potential limitation of the CF is that its calculation gives equal weighting to both of the components that comprise it. This issue was briefly discussed in a review of the possible role of the CF in the development of low back injuries in cricket fast bowlers, where the author proposed that the instantaneous product of axial angular trunk velocity and lateral flexion velocity (ie, not angle) might be more suitable for identifying risk of injury in cricketers [45]. However, this proposal was based on the author's interpretation of ensemble averages presented by Ferdinands et al. [62], so additional work would be required to determine the value of this or similar variants to the CF. Furthermore, while the LBP and NLBP golfers in the present study demonstrated similar CFs during the performance of the full golf swing using a driver, potentially injurious differences may exist in this variable while using the shorter clubs (eg, irons). Research has demonstrated that kinematic profiles differ significantly between the driver and irons, indicating that the shorter clubs tend to place less emphasis on trunk rotation and more emphasis on lateral trunk motion and right-side flexion velocity [63,64]. For this reason, future research may seek to establish the potential influence of the CF in the development of LBP during the performance of a full golf swing using an iron.

As with any research of this nature, there were limitations that should be acknowledged and considered by the reader when interpreting these findings. Firstly, the calculation of the hip and mid-trunk angles using lines joining the hip and shoulder joint centers may have been subject to some error. For example, joint anatomical locations that create the lines are essentially unfixed and can be influenced by other factors. Secondly, the size of the LBP and NLBP sample populations was small (from a statistical standpoint), and for this reason, it is recommended that the reader consider the effect sizes that are reported and support the conclusions. Thirdly, although similar methods of data reduction have been used in previous studies [65–68], it is possible that by analyzing the best performances for each golfer, an element of bias was introduced, as characteristics of performance variability may not have been adequately represented. Finally, given the lack of any significantly different findings between the groups, it is important to recognize that the LBP golfers had a history of golf-related LBP at the time of testing. Therefore, it remains feasible to suggest that higher peak CF values may be evident in the LBP golfers pre-injury and possibly decrease after the onset of symptoms. However, to effectively address this important issue, a well-devised longitudinal investigation would be necessary; however, this was beyond the scope of this study.

Conclusion

The results of this research indicated that golfers with and without LBP did not demonstrate significantly different lumbar CF values throughout the performance of a tee-shot. It is important to identify that although the fundamental concept that underpins the CF seems logical and, indeed, may be applicable to other sports involving large changes in spinal angles and rapid trunk rotation (eg, cricket, javelin), the validity of this measure has not been determined in previous or present research. The presented findings suggest that the CF does not differ significantly between players with and without golf-related LBP, but it remains unclear as to whether the CF profile observed in these golfers is comparable with that which they demonstrated before their injury. Consequently, it is suggested that future research aims to assess the CF longitudinally in the asymptomatic population to determine whether those who develop LBP have an increased peak CF pre-injury and/or an altered neuromuscular recruitment pattern.

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