

Research article

Lower Body Joint Moments during the Golf Swing in Older Adults: Comparison to Other Activities of Daily Living

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Abstract

Golf participation has increased dramatically in the last several years. With this increase in participation, clinicians need better evidenced based strategies to advise those golfers with different pathologies when it is safe to return to the game. Golf teaching professionals also need to understand how to alter golf mechanics to protect injured and/or diseased joints in golfers to allow them to play pain free and avoid further injury. This study used a 3-dimensional link segment model to calculate the net joint moments on the large lower limb joints (knee and hip) during golf (lead and trail leg) and two commonly studied activities of daily living (gait and sit-to-stand) in 22 males, healthy, adult golfers. It also examined the correlations between these knee and hip joint loads and club head speed. The external valgus knee moment and the internal hip adduction moment were greater in the lead leg in golf than in the other activities and were also correlated with club head speed. This indicates a strategy of using the frontal plane GRF moment during the swing. The internal hip extension and knee flexion moment were also greater in the golf swing as compared with the other activities and the hip extension moment was also correlated with club head speed. This emphasizes the importance of hip extensor (i.e., gluteus maximus and hamstring) muscle function in golfers, especially in those emphasizing the use of anterior-posterior ground reaction forces (i.e., the pivoting moment). The golf swing places some loads on the knee and the hip that are much different than the loads during gait and sit-to-stand tasks. Knowledge of these golf swing loads can help both the clinician and golf professional provide better evidence-based advice to golfers in order to keep them healthy and avoid future pain/injury.

Key words: Golf biomechanics, hip joint moments, knee joint moments, club head speed, gait, sit-to-stand.

Introduction

Golf participation has significantly increased in recent years. A 2022 National Golf Foundation report found that 25.1 million Americans currently play golf. That is an increase of almost 10% from 2019 (National Golf Foundation, 2022). Although those numbers are noteworthy, golf's overall reach is much larger, as there are 37.5 million golfers in the US when considering other non-traditional forms of golf participation. These other forms of golf participation include golf entertainment, driving ranges, and indoor simulators (National Golf Foundation, 2022). Golf participation rates in the US continue to be driven primarily

by older adults, as 42% of traditional on-course golf participation is from those 50 years of age or older, while those under 35 years of age make up only 36.5% of golfer (National Golf Foundation, 2022). Since golf participation rates come largely from older adults, and aging increases the susceptibility of joint degenerative diseases like osteoarthritis (OA) (Anderson and Loeser, 2010), clinicians and golf professionals should understand the types and magnitudes of loads that are applied to body during the golf swing.

A typical round of golf includes not only the golf swing, but a significant amount of walking, bending, and stooping/squatting. While walking a typical 18-hole golf course, a golfer may cover between 8.7 and 11.25 km, while taking approximately 11,000 to 16,000 steps (Luscombe et al., 2017). If golfers choose to take a cart when playing golf, understandably they will walk a much shorter, but still considerable, distance (3.18 km) (Luscombe et al., 2017). Although golf has been often considered a low-impact sport with limited chance for injury, the golf swing puts significant mechanical stresses on the musculoskeletal system (Hosea et al., 1990; Lim and Chow, 2000). Although much of the research examining the musculoskeletal loads in golf have been directed towards the lower back, as this is the most injured area in golfers (Gosheger et al., 2003; McHardy et al., 2007), more recent research has identified the importance of the lower body in producing the forces that help create the golf swing (Lynn et al., 2012). While lower limb injuries do occur in golf, injury rates of the lower extremity joints during golf are less coming than upper extremity and lower back injuries (Cabri et al., 2009). This may be due to fact that the literature generally focuses on acute injuries, whereas an analysis of long-term degenerative changes may be more important for lower extremity joints (Kim et al., 2022). Therefore, understanding the contributions of the lower extremity joints to producing the golf swing could not only help golfers avoid pain/injury but also potentially improve golf performance.

One way to quantify the loading of a joint during a movement is to calculate the net joint moment using inverse dynamics (Whittlesley and Robertson, 2014). The net joint moment is the sum or net effect of all the structures that produce moments or torques at the joint (Whittlesley and Robertson, 2014). As the joint moment increases during a movement, the loading of the joint tissues and/or the amount of force required from the muscles crossing the

joint will increase as well. For example, several lower extremity pathologies have been linked to excessive joint moments. Both the frontal plane moments at the knee and the hip during gait have been linked to the development and progression of knee OA (Lynn et al., 2007) and hip OA (Tateuchi et al., 2017), respectively. However, increases in joint moments can also lead to muscular adaptations as increased in the sagittal plane external flexion moment/internal extension moment at the knee and the hip during squatting have been shown to increase the activation of the rectus femoris and gluteus maximus muscles, respectively (Lynn and Noffal, 2012). Joint moments can also be used to determine the relative loading of the joint/musculature occurring during different activities/movements. Another activity/movement that is commonly used to assess the function of the lower body in older adults is the sit-to-stand (STS) task (Alcazar et al., 2018). STS is a common and relatively demanding activity of daily living that has been shown to require larger sagittal plane lower body joint moments as compared to gait (Jevsevar et al., 1993).

Some studies have quantified the net joint moments/loading of the large lower extremity joints during the golf swing (Lynn and Noffal, 2010; Gatt et al., 1998; Foxworth et al., 2013), and compared these values to those presented in the literature for other movements. One study compared loads during the golf swing to other activities of daily living (gait and stair ascent/descent) in older adults (Pfeiffer et al., 2014), but focused only on the knee joint with two kinetic measures (peak knee extensor moment, and peak knee abduction/valgus moment). It is important to note that the loads on the lower limbs in the golf swing are different for each limb due to the nature of the activity (Lynn and Noffal, 2010; Gatt et al., 1998; Foxworth et al., 2013), therefore they must be examined separately. The lead limb in golf is closer to the target (left leg for a right-handed golfer), while the trail limb is further from the target (right leg for a right-handed golfer). Therefore, this study will compare the three-dimensional knee and hip joint loading during the golf swing (both lead and trail limbs) to loading during two standard activities of daily living: (1) gait and (2) STS. It will also determine if there are any correlations between these lower body loads and club-head speed (CHS), a common measure of performance in golf that has been highly correlated with handicap - a measure of overall golf skill level (Fradkin et al., 2004).

Methods

Twenty-two healthy adult males (age: 62 ± 8 years (range 49 - 79 years); height: 1.8 ± 0.1 m, mass: 89.1 ± 10.9 kg) participated in this study. Individuals were excluded if they had back, neck, leg, foot, or arm pain within the last two years, or had undergone any major orthopedic surgery to their lower body or trunk. Prior to participation, each participant read and signed an informed consent document approved by the University Arkansas for Medical Sciences Institutional Review Board. A 10-camera motion capture system (Vicon, Oxford, UK) was used to collect three-dimensional kinematic data during each testing condition. Markers were placed bilaterally on the great toe, lateral and

medial midfoot, medial and lateral malleolus, heel, lateral calf, medial knee joint line, lateral knee joint line, lateral thigh, greater trochanter, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), acromion process, hand, and sternum. Two stationary force platforms (AMTI, Watertown, MA) were used to collect kinetic data from the left foot and right foot. Marker data were sampled at 100 Hz, and force platform data were sampled at 1000 Hz.

Three different movements were tested: gait, STS transfer, and golf swing with a 6-iron. Gait trials were performed barefoot, and participants were instructed to walk on a 10-meter walkway at their preferred pace. Gait trials continued until three good trials of complete data were captured. Good trials were defined as ones where the subject walked naturally and had their feet land entirely on the force plates without targeting.

STS trials were performed barefoot, and participants sat with their feet placed on the center of each force platform on a standard height chair (46 cm) which represents an average public seat height (Eekhof et al., 2001). They were asked to continuously sit down and stand up from the chair as quickly as possible for 30 seconds while their arms were extended forward to exclude differences in upper body momentum generation (Stevermer and Gillette, 2016). To obtain the most reliable STS trials and minimize fatigue effects, we selected the middle three cycles of the STS transfers that had consistent peak estimated center of mass velocities.

During the golf swing trials, the participants all wore the same model of golf shoe (NIKE Zoom Trophy) and were asked to hit the golf ball with a 6-iron into a net placed 5 m in front of them, targeting at a piece of string on the net. Each participant was allowed as many practice swings as they wanted to warm up and then performed shots using their six-iron. Eight shots were recorded (Severin et al., 2019), and three golf swings were analyzed. Marker and force platform data were filtered using a fourth-order, symmetric low-pass Butterworth filter at a cut-off frequency of 6 Hz. The force data were down sampled from 1000 Hz to 100 Hz. Doppler radar technology (TrackMan Golf, Vedbæk, Denmark) was used to measure CHS during golf swing trials.

During the gait trials, heel strike and toe-off were detected with 5% BW thresholds for vertical ground force (Hall et al., 2012). The start and end of the STS transfers were determined by changes in vertical ground reaction force and center of mass velocity (Stevermer and Gillette, 2016; Pai and Rogers, 1990). Segment masses, center of mass locations, and moments of inertia were obtained according to an anthropometric model (De Leva, 1996). Knee and hip moments in the sagittal and frontal planes were analyzed during the entire stance phase of gait, STS transfer, and golf swing. Joint moments were transformed to the distal segment coordinate system axes and reported as internal joint moments except for the frontal plane knee moments, which were reported as external joint moments. Knee and hip moments in the sagittal and frontal planes were calculated using inverse dynamics and rigid body assumptions. All calculations were performed using custom MATLAB code.

Peak net joint moments during each movement were then extracted from the curves and normalized to body mass. A repeated measures ANOVA was then used to determine differences in peak moments between the three movements (golf - lead and trail leg, gait, STS). Pearson product-moment correlation coefficients of CHS to average peak net joint moments were also calculated. Then, those peak net joint moment which were significantly correlated to CHS were entered into a hierarchical linear regression to determine how much variance in CHS can be explained by the lower body net joint moments. Significance level was set at $\alpha < 0.05$.

Results

The mean 6-iron CHS for the group was 33.5 ± 4.3 m/s. Mean net joint moment data are shown in Table 1. Examining the results presented in Table 1, any observed differences between the gait and STS condition will not be discussed, as this was not the focus of this manuscript. Notable findings include the greater external knee valgus moment ($F(2.082) = 14.837$, $p < .001$) on the lead side in golf as compared to the trail side ($p = 0.033$) and both other activities ($p < .001$). Also, the internal knee flexion moment ($F(1.710) = 29.112$, $p < .001$) on the trail side during golf is greater than the two other activities ($p < .001$) and the moment on the lead leg in golf ($p = .023$); however, the internal knee flexion moment on the lead side in golf is similar to the loads in gait ($p = 1.000$), but greater than STS ($p = .003$). For the hip, the internal adduction moment ($F(1.654) = 27.002$, $p < .001$) is greater in both legs in golf as compared with the gait (lead hip $p < .001$, trail hip $p = .002$) and STS (both $p < .001$), and the lead hip moment is greater than the trail hip moment in the golf swing ($p = .017$). Finally, the internal hip extensor moment ($F(2.325) = 80.578$, $p < .001$) is greater in both legs during the golf

swing when compared to gait and STS (all comparison $p < .001$), and the trail hip moment is greater than the lead hip moment in golf ($p = .022$).

The correlations between CHS and each of these peak moments in the lead and trail legs are shown in Table 2. Table 2 shows that there were four significant correlations between peak joint moments and CHS. The lead leg valgus knee moment explained 33.3% ($p = .005$) of the variance in CHS, while the lead leg hip adduction and extension moments explained 21.5% ($p = .030$) and 21.3% ($p = .030$), respectively. Finally, the hip flexion moment on the trail leg explained 19.6% ($p = .039$) of the variance in CHS.

Table 2. Correlations (r) of peak joint moments in the Lead Leg and Trail leg during golf to Club Head Speed. Significant correlations at $p < 0.05$ denoted by bolded values*.

	Golf Lead Leg	Golf Trail Leg
Varus Knee	0.407	0.168
Valgus Knee	0.577*	0.190
Knee Extension	0.381	0.063
Knee Flexion	0.096	0.416
Hip Abduction	0.210	0.208
Hip Adduction	0.464*	0.008
Hip Extension	0.462*	0.147
Hip Flexion	0.010	0.443*

The hierarchical linear regression revealed that the strongest correlated net joint moment, the external lead knee valgus moment, predicted 33.2% of the variance in CHS and was significant ($p = .005$). The internal lead hip adduction moment added another 3.8% variance explained but was not a significant predictor of CHS ($p = .301$). The internal lead hip extension moment and trail hip flexion moment were also not significant predictors of CHS and explained another 10.5% ($p = .074$) and 0.6% ($p = .656$), respectively.

Table 1. Mean (SD) of net joint moments for the knee and the hip in the sagittal and frontal planes during gait, sit-to-stand, and golf swings. All data presented as Mean in Nm/kg. All moments presented as internal moments except the knee varus and valgus moments.

	Gait	Sit-to-Stand	Golf Lead Leg	Golf Trail Leg
Varus Knee	0.395(0.134)	0.125(0.058) a	0.527(0.212)	0.517(0.133)
Valgus Knee	-0.165(0.146)	-0.117(0.969)	-0.552(0.359) a	-0.271(0.270)
Knee Extension	0.445(0.166)	0.898(0.275) a	0.595(0.275)	0.465(0.259)
Knee Flexion	-0.334(0.141) a	-0.098(0.078) b	-0.410(0.339) a	-0.682(0.192) c
Hip Abduction	0.728(0.141)	0.294(0.091) a	0.696(0.302)	0.794(0.240)
Hip Adduction	-0.124(0.83) a	-0.110(0.142) a	-0.878(0.541) b	-0.436(0.308) c
Hip Extension	0.411(0.187) a	0.783(0.169) b	1.17(0.371) c	1.458(0.254) d
Hip Flexion	-0.683(0.162) a	-0.219(0.234)	-0.269(0.147)	-0.405(0.285)

Different superscript letters (a,b,c,d) indicate a statistical difference between movements/legs ($p < .05$).

Discussion

The purpose of this study was to compare the loading of the large lower extremity joints during the golf swing to two other commonly studied activities of daily living: gait and STS. It also sought to determine if there were correlations between the loading of the large lower extremity joints and CHS, which is highly correlated with golf score/skill level (Fradkin et al., 2004). The main findings of this study are: (1) the external valgus knee moment on the lead leg during golf is larger than the trail leg and both other activities (gait and STS); (2) the internal knee flexion

moment on the trail leg during golf is greater than the lead leg and both other activities (gait and STS); (3) the internal hip adduction moment and hip extension moments were larger during a golf swing on both legs than in gait or STS; (4) there were moderate correlations between CHS and the valgus knee, hip adduction, and hip extension moments on the lead leg in golf the hip flexion moment on the trail leg in golf.

The finding of the large valgus moment on the lead knee in golf coincides with previous findings in a younger and more skilled population of golfers (Lynn and Noffal, 2010). This large valgus load on the knee joint has been

prospectively linked to degenerative disease in the lateral knee compartment (Lynn et al., 2007) and anterior cruciate ligament injury (Hewett et al., 2005); therefore, clinicians may need to be cautious when advising patients with these types of pathologies in their lead knee when it is safe to return to golf. These data suggest that the golf swing could be painful and/or slow the healing/rehabilitation process in those with lateral compartment knee pathology or ACL injury. This valgus moment on the lead knee in the golf swing peaks in the early part of the downswing, but the mechanics of how this moment is produced is variable amongst the participants in the study. Some golfers produce a large laterally directed ground reaction force (GRF) off the lead foot (Figure 1a), while other golfers collapse the lead knee into a valgus position while producing a large vertical GRF (Figure 1b). It should also be noted that this lead knee valgus moment is correlated with CHS (Table 2). It can be hypothesized that those who attempt to increase the GRF frontal plane moment to add angular momentum to the system and speed up the club (Han et al, 2019) likely increase this valgus knee moment in the process. Producing this large laterally directed GRF would increase the valgus moment on the knee and could increase the moment arm between the body center of mass (COM) and the combined GRF vector, thus adding more angular momentum to the system in the frontal plane. However, the correlation of this valgus knee moment to CHS in this work, and the correlation of the frontal plane GRF moment to CHS in Han et al. (2019) are moderate correlations that explain a small amount of the variability in the speed of the club at impact. Therefore, altering swing technique to emphasize other methods of producing CHS in those with lateral knee and/or ACL pathologies (i.e., using the pivoting moment which emphasizes use of anterior posterior GRFs) (Han et al, 2019) could be useful in avoiding further damage and allowing them to return to golf pain free.

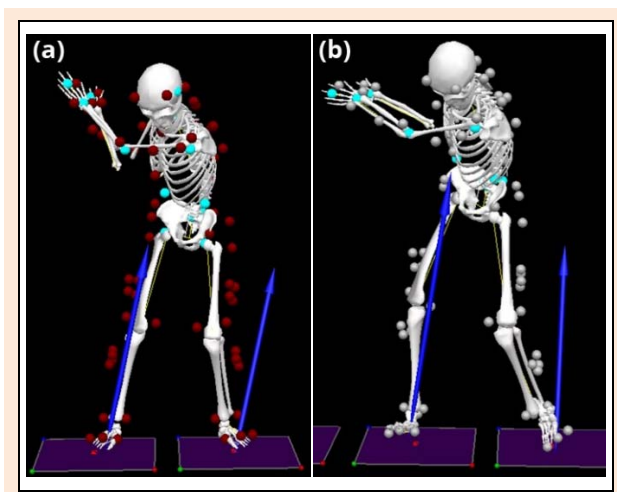


Figure 1. Animations showing the peak external valgus knee moment and peak internal hip adduction moment on the lead leg in the early part of the downswing. Two different methods are shown here to cause a large external valgus moment on the lead knee: (a) keeping the knee aligned over the foot while producing a large laterally directed ground reaction force, (b) allowing the knee to collapse into a valgus position while producing a vertical ground reaction force.

The finding that the internal knee flexion moment is largest in the trail leg in golf as compared to gait, STS, and the lead leg in golf is novel to the best of our knowledge. Pfeiffer et al (2014) measured this moment but only extracted the internal knee extension moment peak variable for analysis. However, our results seem to coincide with their results (Pfeiffer et al., 2014) as the waveform of the lead knee in golf is the only one of the activities they compared (gait, stair ascent, stair descent, lead knee golf, trail knee golf) that has a large negative (internal flexion moment) peak. This moment peaks in the early part of the downswing when the golfer is producing an anteriorly directed GRF from their trail leg in order to initiate the rotational component of the downswing (Lynn et al., 2012) or the pivoting moment (Han et al., 2019). Figure 2a shows an example animation of the frame during the swing where this moment peaks. This moment would put a large external load on the hamstring/knee flexor musculature during the swing, so clinicians should be careful when advising golfers with trail leg hamstring issues when it is safe to return to golfing.

Our results differ from Pfeiffer et al. (2014) when it comes to the peak internal knee extension moment. They found the moment during gait was less than the lead knee but greater than the trail knee in golf; whereas we found this moment was of similar magnitude during gait and in both knees in golf. This difference could result from the fact that Pfeiffer et al. (2014) tested driver swings while this work examined swings with a 6-iron. Our work suggests that the knee extension moment during STS is larger than the moment created in either knee during golf, so clinicians can be confident in allowing those with quadriceps weakness to return to golf once they are comfortable performing a STS task.

This current work also found that the internal hip adduction moment on both legs during golf is greater than during gait or STS. It also found that this moment was larger on the lead leg. These results seem to contradict the results of Foxworth et al. (2013) as they found the trail leg adductor moments during golf were larger than the lead leg adductor moments in both their young and senior groups; however, they did not compare the golf moments to any other tasks. This difference may also be related to the club tested, as Foxworth et al. (2013) tested driver swings, while we examined 6-iron swings. The differences in strikes between a driver struck off a tee, which will more often have a positive angle of attack (i.e., club moving up at impact) and the club reaching its low point behind the ball, and a 6-iron struck off the ground, which will more often have a negative angle of attack (i.e., club moving down at impact) and the club reaching its low point in front of the ball, could account for these differences. The internal hip adduction moment in the lead leg during the golf swing generally peaks around the same time as the knee valgus moment in the lead leg, when the GRF acts lateral to the hip and knee joint in the frontal plane due to a laterally directed GRF (Figure 1). Hip adductor weakness is common in those with several pathologies such as symptomatic femoroacetabular impingement (Casartelli et al., 2011) and medial knee OA (Hinman et al., 2010); therefore, clinicians should be very

careful before clearing patients with any kind of hip adductor weakness/pathology to return to golf, especially if the golfer's lead side adductors are involved. Golf coaches should also consider using a technique that emphasizes the use of the pivoting moment (i.e., anterior-posterior GRFs) rather than the frontal plane moment (i.e., medial-lateral GRFs) (Han et al., 2019) in golfers with hip adductor weakness/pathology.

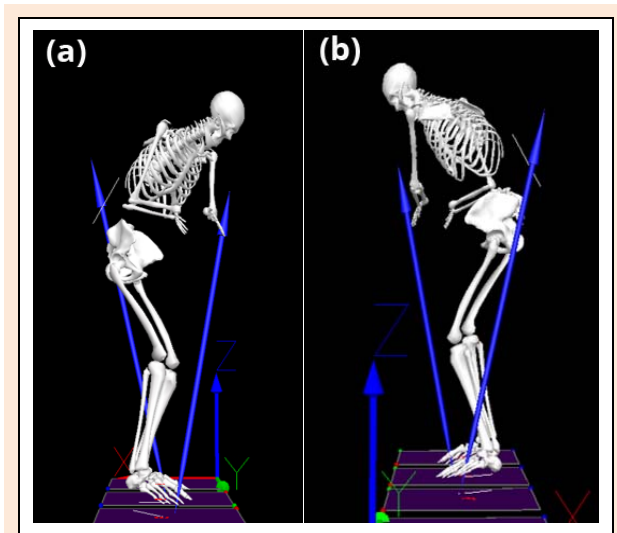


Figure 2. Animations showing (a) the peak internal hip extension moment on the trail leg, and (b) peak internal hip flexion moment on the lead leg, in the same golfer in the mid down swing. Note: in (a) we are examining the golfer looking towards the direction of travel of the golf ball (from right/trail side to left/lead side), while in (b) we are looking back at the golfer away from the direction of travel of the golf ball (from left/lead side to right/trail side).

It was also discovered that the hip extensor moments during golf are much larger than during gait and STS. When compared to the hip moments during gait, the hip extensor moments are on average approximately $3.5\times$ greater on the trail side hip, and more than $2.5\times$ greater than gait on the lead side hip. When these moments are compared to STS, the hip extensor moments are almost $2\times$ greater on the trail hip and almost $1.5\times$ greater on the lead hip. This result is supported by the work of Foxworth et al. (2013) as they discovered that the trail side hip extensor moments were much greater in magnitude than the lead side moment, but once again, these moments were not compared to any other activities of daily living. It has also been found that golfers activate the trail side gluteus maximus to almost 100% of maximum voluntary contraction during the swing (Bechler et al., 1995), since there is such a large moment on the hip during the swing, it makes sense that golfers should maximize activation of the largest hip extensor muscle (i.e., gluteus maximus) (Ito et al., 2003). This emphasizes the importance of hip extensor strength and specifically gluteus maximus activation in golfers. Gluteal weakness has been linked to pathologies in several parts of the body including the lower back and the knee (Rieman et al., 2009; Powers, 2010; Himmelreich et al. 2008). Due to the excessive extensor load on hip during the golf swing, gluteal muscle function may need to be evaluated before clearing a patient to return to golfing. Clinicians should also explore the potential of using golf swings

as an exercise to activate the gluteal muscles, which could have beneficial ramifications in other ADLs.

When examining the correlations between peak joint moments and CHS, there were four significant correlations discovered. These individual variables only produced moderate correlations and explained a total of 48.1% of the variance in CHS, indicating that there are several different strategies used by subject to load the joints and create CHS. The correlations between the lead knee external valgus moment and the lead hip internal adduction moment, which produced the strongest correlations and explained the most variance in CHS, both indicated a common strategy of using more medial-lateral and vertical GRFs to increase the “frontal plane moment”, add angular velocity to the system and create CHS (Han et al., 2019). Figure 1 depicts two different golfers mainly employing this strategy. Another strategy to increase CHS could be related to the correlations between the internal lead hip extension moment and the trail hip flexion moment, although these were not as strongly correlated and explained less of the variance in CHS. Golfers who employ this strategy are attempting to produce more anterior-posterior GRFs in opposite directions with each foot to create a force couple in the transverse plane (Lynn et al., 2012). This involves the golfers creating more “pivoting moment” (Han et al., 2019) to add angular momentum to the system and speed up the club. Figure 2 shows a golfer employing this strategy. Every golfer uses some combination of these two strategies in their swing and a collaboration between the clinician and the golf professional could be very beneficial to ensure each golfer is producing the safest and most efficient swing mechanics for them. Future research should examine techniques that could be used to alter swing mechanics and shift the loads off injured/diseased joints while still allowing the golfers to maintain performance (i.e., CHS).

Some limitations of the current work include that only 6-iron swings were included in the current analysis, since golf swings with the driver would create higher CHS, it can be hypothesized that this would also increase joint moments, further research should investigate this question. Another limitation is that gait and STS trials were done barefoot, while golf swing trials were done in a standardized golf shoe with soft spikes on them. The spiked golf shoes were too dangerous to wear for gait and STS trials due to the lack of friction between them and the laboratory flooring, and since we did not have standardized footwear for these other tasks, we chose to do these trials barefoot. This manuscript also did not examine the individual GRFs and their connection to joint moments. Since there are many commercially available systems available to golfers and golf instructors now to measure GRFs, future work should examine the connections between these individual GRF values and joint moments/joint loading.

Conclusion

The golf swing places some loads on the knee and the hip that are much different from the loads during gait and STS tasks. Namely, the internal valgus moment on the knee and external adduction moment on the hip. Both moments also had a weak correlation and explained the most variance in

CHS, which indicates that some golfers emphasize a strategy employing the frontal plane moment to produce the momentum needed to swing the club. Alternatively, the internal hip extension and knee flexion moments were also greater in the golf swing as compared to the other activities. The hip extension moment on the lead leg and the hip flexion moment on the trail leg were also weakly correlated and explained some variance in CHS, which indicates that some golfers emphasize the pivoting moment using anterior-posterior ground reaction forces to give momentum to the club. Knowledge of these golf swing loads can help the clinician better advise patients when it is safe to return to golf participation after injury/surgery and better tailor their advice to the individual pathologies of their patient. It can also help the golf teaching professional tailor their instruction in order to emphasize a strategy that may protect the injured/diseased tissues and allow the golfer to play pain/injury free.

Acknowledgments

There is no conflict of interest. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

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Key points

- Several joint moments during the golf swing on the lead side (external knee valgus, hip adduction, hip extension) and the trail side (knee flexion, hip adduction, hip extension) were greater than the moments on the joints during gait and sit-to-stand.
- Several joint moments during the golf swing on the lead side (external knee valgus, hip adduction, hip extension) and on the trail side (hip flexion) were correlated to club head speed.
- Knowledge of the loading of the joints during the golf swing can help clinicians and golf professionals better advise golfers in ensuring their safe participation in this lifetime sport.

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