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Original Article

Knee kinematic during the golf swing: a cross-sectional analysis between groups of different handicap

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Abstract
Introduction: Golf is played by more than 50 million of people worldwide. The swing is the fundamental movement, and it is repeated many times during practice and competitions. Knee injuries are frequent in golfers and the mechanism of injuries is different considering their level. Few authors have investigated leg kinematics and differences of motor pattern between pro-player, mid-players and beginning players have not been fully investigated. The goal of this study was to analyse knee biomechanics by measuring the oscillatory differences on the left knee in ecological conditions. We analysed those difference in three group of players according to their handicap. **Methods**: 18 right-handed golfers were recruited. The sample was divided into three group according to their handicap: four pro-player (0-11.4), five middle level (11.5-26.4) and nine beginners (26.5-54). To analyse the acceleration of the knee, we used a tri axial Shimmer3 sensor, and we used ZeppGolf to choose the best shot performed by the players. **Results**: There was a statistical difference between group 1 and group 2 in both the frequencies analysed at 1-2Hz ($p<0.001$) and 2-3 Hz ($p<0.004$). Between group 1 and 3 in 2-3 Hz frequency ($p<0.0008$) and between group 2 and 3 at 1-2 Hz ($p<0.012$). **Discussion**: Data was coherent with those in the literature and shows a significant difference between groups in terms of acceleration. The pro-players were considerably faster than the other two group of players, considering the knee acceleration but also for some parameters on the upper limb. Middle level players showed an unsmooth motion with a huge acceleration and deceleration during the swing. Surprisingly considering the knee the amateur players showed a smooth movement but in a restricted range of motion. All this difference was in the voluntary frequency band for every class of players so it could be modified with training. **Conclusion**: Our result was coherent with literature. The data showed that pro-players reach a greater acceleration on knee joint, comparing to mid-level and beginner golfers. Our goal was to enrich the kinematic data about the golfers considering their handicap level because knowing difference between players could improve the capability to prevent injury and to train golfers properly.
Keywords: Knee kinetic, ZeppGolf, Biomechanics, golfers, knee injury

Introduction

Golf is played by more than 50 million people worldwide. In 2019, the Italian Federation of Golf (FIG) estimated that it had 90,299 members. Swinging is the fundamental movement of golf, and this action is repeated many times during practice and competitions. This gesture is the main cause of injuries for pro players and amateurs for different reasons. Professional golfers have frequent knee injuries due to overuse, whereas amateur golfers become injured due to poor technique and technical errors or deficiencies[1,2,3]. A recent systematic review reported that 3–18% of golfing injuries occur at the knee and that, even though golf is considered a ‘low-impact’ sport, the prevalence of knee injuries is comparable to high-impact sports, such as basketball (Baker et al. 2017[4]). The anterior cruciate ligament (ACL) and the lateral compartment of the knee are the most stressed structures, especially during the impact and follow-through phases, as shown by Purevsuren et al.[5] (2020) and Carson et al.[6] (2020).

The present literature affirms that the left knee (in right-handed players) shows higher movement degrees in all planes compared to the right knee during all movements[4,7,8,9]. Kinematic studies have identified that the lead knee is subject to rapid knee extension at the area of lower knee flexion (0–30°)[7,8,10,11,12,13] and due to a high amount of knee internal rotation[7,13,14,15] during a forward swing. An increased anterior tibial translation with respect to the femur in the lead knee has been observed at ball impact[15]. This joint range is associated with greater swing speed and major articular compression caused by muscular activation, which exposes pro players to a higher risk of injury (Purevsuren et al. 2017[16]). Considering the incidence of knee injuries and the differences in risk injury factors between pro and amateur players, understanding different specific techniques used by golfers seems fundamental. Nevertheless, few authors have investigated leg kinematics; instead, they have focused on analyses of upper limb and trunk biomechanics. Differences between pro, mid-level and

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beginning players have not been fully investigated[17]. Somjarod et al. (2011[13]) demonstrated that pro players have a higher articular range of motion compared to amateurs; therefore. There is higher flexion on the backswing and greater extension during the impact and follow-through phases. Moreover, the pro group showed a greater left knee angular velocity[13]. Choi et al. (2015[18]) found that pro players seemed to be more capable of distributing higher force on the joint despite their higher range of motion and faster gestures, even if the compressive forces on the knee appeared to be extremely high.

They found peak extension moments of approximately 0.5–0.7 Nm.kg−1 in the lead leg during the downswing in skilled golfers; however, clear extension peaks were not evident in the lead leg data of the unskilled group[18]. Lindsay et al.'s (2008) literature review found that pro golfers exhibit increased force production, efficiency and performance consistency relative to less-skilled golfers[19]. Conversely, Kim et al. (2017) demonstrated that compared to an elite group, there was a significant difference in the maximal and minimal angles of the lead knee in an amateur group. They found that the motions in the lead knee joint were larger in the amateur group (31°) than in the elite group (26°), but there was higher angular velocity in the amateur group (306.1 m/s2) than in the elite group 244 m/s2[20]. In a conflicting scenario, understanding how an individual manages the reaction force generation between the legs as well as multi-joint control of each leg could provide players and coaches with a mechanistic foundation to design interventions that may facilitate improvements[21].

The goal of this study is to analyse knee biomechanics in right-handed players by measuring the oscillatory differences on the left knee under ecological conditions (i.e., during normal field practice). We aim to improve the available knowledge about the differences between different levels of players. To recognise a different pattern of movement, this study will analyse different knee movements according to different players' abilities, which could lead to different rehabilitation, prevention, treatment, and training plans. To the best of our knowledge, the current literature considers pro players as those with a handicap of 0–11.4 and mid-level players as those with a handicap of < 26.4. To date, no studies have considered low-level/beginning players (i.e., those with a handicap between 26.5 and 54). To consider these players, we created three assessment groups to properly analyse different motor patterns.

Materials and Methods

Participants: In total, 18 right-handed golfers (11 male and 7 female) between 13 and 65 years of age with golf handicaps between 4 and 54 were recruited for this study. Before starting the assessment, the participants signed an informed written consent form to participate in the project. The participants then completed a questionnaire that asked for their personal data, including previous injuries or diseases. A history of knee disorders was an exclusion criterion. Participants were divided into three groups by handicap[22]: pro players (handicap = 0–11.4), mid-level players (handicap = 11.5–26.4) and beginners (handicap = 26.5–54).

Procedure: The assessments were done on a golf mat in an ecologic setting. The participants were recruited before they started their training sessions. A five-minute warm-up was allowed before starting the assessment. One wireless inertial triaxial Shimmer3 sensor (www.shimmersensing.com) was used for the kinematic analysis; it provided kinematic data from the knee in real time at 200 samples/s. The Shimmer sensor was connected to a laptop that ran the application ConsenSys Basic. The sensor was positioned on the tibial tuberosity and stabilised with an elastic band. We measured the movement in two different frequency bands: 1–2 Hz and 2–3 Hz. The Zepp Golf (http://www.zepplabs.com/en-us/golf/) tool was used to provide estimates on practicability issues when using this device in the field; the inertial sensor system can be used by any individual with any type of equipment, as suggested by Luckemann et al.[23] Zepp Golf was applied on the left-hand golf glove and calibrated, as described by Luckemann et al[23]. A 30-fps video camera was positioned laterally to the athletes to accurately assess the starting and ending movements of the swing. The athletes were asked to perform 10 swings with a 7-iron golf club. The physiotherapist asked them to hit the ball to the best of their ability. The number of swings was selected based on an analysis by Severin et al. (2019), which suggested that the optimal number of trials for biomechanical research on participants during a golf swing was between 4 and 12[24]. For the kinematic analysis, we selected the five best shots, considering the data collected using the Zepp Golf tool.

Data collection and statistical analysis: The inertial Shimmer3 sensor extracted the signal related to the swing; this signal was synchronised with the video camera, and the shot was segmented manually. Data were composed of 3 triaxial vectors, with a sampling frequency of 200 samples/s and a mean length of 2.77 seconds. All accelerometer data processing calculations were performed using MATLAB Version 9.3 (R2017b). The accelerometric signal was filtered with a Butterworth band-pass filter with a cut-off frequency of 0.2 Hz, which allowed us to eliminate the gravitational force; the other cut-off was settled at 15 Hz to reduce the noise outside the physiological band. From this resulting signal, we extracted the magnitude because the orientation of the sensor was deemed too inaccurate for our intended purposes due to the ecological conditions of the study. The power spectral density (PSD) estimate of these signals was calculated with the MATLAB periodogram function with a rectangular window and a resolution of 2 Hz. The band frequency was divided into three groups, which were selected according to the players' handicap level. The Wilcoxon Mann–Whitney non-parametric test[25] was applied to analyse the statistical differences between the three groups. The mean and standard deviation of the spectral power for each frequency band were assessed. Sample and Zepp Golf data were analysed with R 3.6.2 software.

Results
The sample was divided into three groups according to their national ranking levels. Table 1 shows the distribution of the participants in the three groups.

	Gender M, F	Mean Age±SD	Mean Handicap±SD
Group 1(Handicap 0–12)	M = 4 (100%) F = 0	38 ± 18.5	7.25 ± 3.5
Group 2(Handicap 13–25)	M = 3 (60%) F = 2 (40%)	55.8 ± 6.4	19.6 ± 2.6
Group 3(Handicap 26–54)	M = 5 (55%) F = 4 (45%)	46 ± 21.7	41 ± 12.1
Sample	M = 12 (66.6%)F = 6 (33.4%)	46.9 ± 18.3	27.7 ± 17

Table 1 Sample characteristics
To choose the five shots, we used data from the Zepp Golf tool. Table 2 shows the mean results obtained with this device. The data were analysed with the non-parametric Wilcoxon rank sum test[25].

	Group 1	Group 2	Group 3	P value
Clubhead speed (km/h) mean ± SD	144.6 ± 7.2	117.8 ± 16.9	112.5 ± 16.1	0.024
Hand speed (km/h) mean ± SD	29.1 ± 5	25.8 ± 3	22.8 ± 2.5	0.116
Back swing (°) mean ± SD	236.2 ± 7.3	239.3 ± 15.2	231.0 ± 29.3	0.855
Downswing time (sec) mean ± SD	0.24 ± 0.02	0.39 ± 0.02	0.34 ± 0.06	0.007
Clubhead plane (°)	5.1	11.9	13.5	0.009
Hand plane (°)	-0.6	5.2	5.8	0.011
Shot total score (0–100) mean ± SD	87.3 ± 7.2	81.7 ± 9	82.1 ± 6.9	0.562

Table 2 The average score of every item obtained by Zepp Golf. SD = standard deviation.

Kinematic data: The accelerations recorded by the sensor through the five shots with the highest score on Zepp Golf were analysed below. Acceleration was measured using PSD. The frequency range in which we identified the differences between the groups was 1–2 Hz and 2–3 Hz. This range encounters voluntary movement frequencies: therefore, we could assume that athletes could modify this movement. The data were analysed with the non-parametric Wilcoxon rank sum test[25].

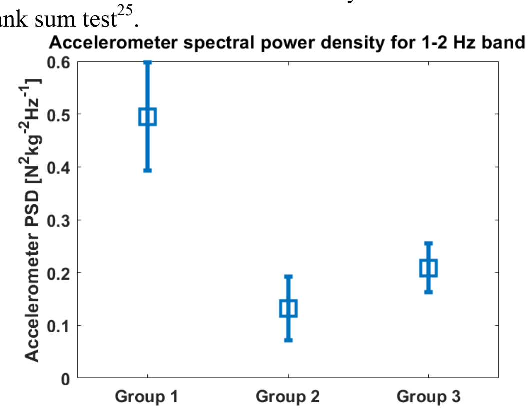

Figure 1 PSD acceleration detected from the sensor applied on the knee at frequencies between 1–2 Hz.
Figure 1 shows a statistically significant difference between groups 1 and 2 ($p < 0.001$**) and groups 2 and 3 ($p < 0.012$*).

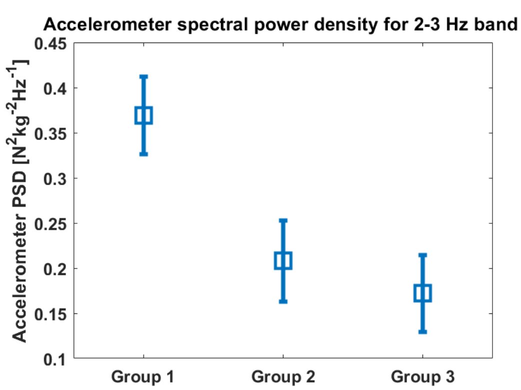

Figure 2 PSD acceleration detected from the sensor applied on the knee at frequencies between 2–3 Hz. The square represents the mean, and the error bars represent the standard error (standard deviation/√(total subjects)).

Figure 2 shows a statistically significant difference between groups 1 and 2 ($p < 0.004$**) and groups 1 and 3 ($p < 0.0008$***).

	Group 1 [$N^2kg^{-2}Hz^{-1}$]	Group 2 [$N^2kg^{-2}Hz^{-1}$]	Group 3 [$N^2kg^{-2}Hz^{-1}$]	Frequency band [Hz]
PSD mean ± SD	0.4955 ± 0.4334	0.1319 ± 0.2554	0.2088 ± 0.1952	1–2
PSD mean ± SD	0.3692 ± 0.1822	0.2079 ± 0.1899	0.1721 ± 0.1811	2–3

Table 3 Summary of the data expressed in Figures 1 and 2. PSD = power spectral density; SD = standard deviation.

Discussion

The goals of this study were to analyse left knee acceleration during a swing and the difference in this acceleration between three groups of athletes with different skills. The analysis was based on the frequency of the voluntary range of motion of the knee joint. The data showed that the most significant statistical difference between groups was at the 2–3 Hz frequencies between the pro player group and the beginner group ($p < 0.0008$***). This means that acceleration differed significantly between these two groups, considering the left knee during the swing. In addition, at this frequency band, there was a statistically significant difference between pro players and the mid-level players ($p < 0.004$**). There was also a significant difference in the frequency band between 1–2 Hz between pro players and mid-level players ($p < 0.01$*).

These data correlate with those in the literature. Notably, the skilled players showed a huge velocity variation during their swings compared to the other groups. In the analysis, we excluded gravity and other external forces that could interfere with the movement; for this, we can affirm that the acceleration was due to muscular activation and belonged to the modifiable range of movement. Many professional golfers and coaches have stated that the legs are important for achieving an efficient swing and the maximum speed of the club head[27].

Thus, we could assume that this huge acceleration is functional for performance, but it could lead to an increased risk of knee injury because the intra-articular structures are highly involved in swing gestures (Kim et al. [26], Purevsuren et al.[5]). Moreover, Carson et al. [6] demonstrated a correlation between lead knee peak abduction moment and clubhead speed; therefore, the differences that we found in the Zepp Golf measurement could be linked to this. The data show a quick knee extension on the pro players; this movement, as suggested by Purevsuren et al.[16], leads to significant intra-articular compression. The combination of intra-articular compression, a higher Range Of Motion (ROM) Somjarod et al.)[13] and a higher acceleration movement, as suggested by our data could all be considered risk factors for increased knee injury risks in high-level athletes.

The kinematic analyses of the beginners and the mid-level players added value to our study. A statistically significant difference between groups 2 and 3 ($p < 0.012$*) in 1-2Hz band was found. To properly analyse the difference between middle level and beginner a qualitative analysis could be carried out. In addition to the significant difference on 1-2Hz band, the most interesting factor was the difference in acceleration between the two groups in the two band frequencies analysed.

The difference between the two band frequencies in the mid-level players was -0.076 m/s; in the beginners, this difference was +0.036/s. This means that the mid-level players had higher acceleration and deceleration during the swing movement, which was always in the voluntary range of muscular activation. This motor pattern led to an unsmooth motion. A lack of muscular control during movement (Choi et al.)[10] and the desire to increase their swing performance could be the reasons for this kind of motor activation. Moreover, the greatest acceleration on the last part of the movement, without proper motor control, could lead to significant intra-articular compression, which could be considered a risk factor for these athletes (Purevsuren et al.)[16].

Conversely, the beginners showed a more continuous and smooth motion in their swings, but they did so in a restricted articular range compared to the other groups. Therefore, incorrect techniques could be a possible mechanism of injury. Our results correlate with the previous literature. The pro players used a higher acceleration movement in the voluntary frequency band, which could lead to intra-articular compression and repetitive execution of the gesture. It is also interesting to highlight the differences between mid-level and beginner players. Notably, the mid-level players seemed to try to accomplish better performance by increasing the acceleration movement on the left knee, which could cause a movement that they could not properly control and thus could be a risk for knee injuries. By contrast, the beginners showed a smoother but slower motion swing with lower acceleration or deceleration during the gesture. In these players, the late activation of the vastus medialis during follow-through could increase the dynamic angle in the valgus, thereby increasing the risk of an ACL tear[28]. Our study used Zepp Golf to choose which shots to analyse.

The Zepp Golf tool provided data that aligned with the results of the sensor. There was a statistical difference in the clubhead speed, downswing time, clubhead plane and hand plane between the pro players and the other two groups. Therefore, the increasing skill of the player probably allows for greater acceleration and a higher range of motion in the entire body, not only in the lower limbs.

Conclusion

Studies comparing golfers' abilities may increase our knowledge about biomechanics and provide golf coaches with additional information that will allow them to coach a variety of players. This biomechanical knowledge could be fundamental for health professionals who work with golfers to create coherent prevention protocols. Considering our results and the previous literature, the differences related to the handicap between the athletes are important for golf trainers, physical therapists and all professionals who work with these players. The results show a statistical difference between pro, mid-level and low-level players in acceleration on the lead knee. These data are consistent with the present literature in that considering pro players shows that movement in the knee could be the mechanism that generates the highest load on the ACL, and this element is considerably different from the classic injury mechanism in dynamic valgus loading. Our results also found different accelerations between low- and mid-level players. Beginners showed smoother movement compared to mid-level players, but they had a shorter range of motion. In all the golfers analysed, these accelerations were part of the voluntary frequency band; therefore, it could be possible to modify them to increase performance and decrease the risk of injuries. Given these findings, different training and prevention activities could be managed by considering the skills of the athlete.

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