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Advance Research on Foot and Ankle

Research Article

Castro MA, et al. Adv Res Foot Ankle: ARFA-109.

DOI: 10.29011/ ARFA-109.100009.

Lead and Trail Legs Ground Reaction Forces and Timing During the Golf Swing with Different Clubs in Average Golfers

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Citation: Castro MA, Fernandes O, Silva L, Marta S, Vaz J, et al. (2018) Lead and Trail Legs Ground Reaction Forces and Timing During the Golf Swing with Different Clubs in Average Golfers. Adv Res Foot Ankle: ARFA-109. DOI: 10.29011/ ARFA-109.100009.

Received Date: 21 November, 2018; **Accepted Date:** 04 December, 2018; **Published Date:** 13 December, 2018

Abstract

The current study described medial-lateral anterior-posterior and vertical maximal GRF and the time in phase when that peak occurred during a golf swing performed by average golfers with three different clubs. Concerning the maximal GRF in both lead and trail leg, our study shows that the swing with the three clubs used is similar. Significant differences occur in the anterior-posterior peak GRF at the downswing just for the trail leg. This study approached the time of peak GRF occurrence normalized for all subjects allowing to better compare different phase durations. Differences in time of peak are mostly found close to the moment of impact, acceleration (pitching wedge and 7-iron) and early follow through for the vertical GRF lead leg. We also found significant differences during the backswing with pitching wedge and 4-iron, for the anterior-posterior GRF trail leg, during the backswing between pitching wedge and 4-iron, during the forward swing and acceleration between pitching wedge and 4-iron and finally in the early follow-through between pitching wedge and 7-iron on medial lateral GRF trail leg. GRF peak and timing knowledge when using different clubs may assist coaches and golfers when deciding strategies to optimize performance as well as in under¬standing the swing impact in the body and the risk it represents to suffer an injury. Decisions concerning maintaining sport activity or returning to sport must take into account that in anterior-posterior plane the use of clubs for short, intermediate or long distance implies different maximal GRF.

Keywords: Average Golfer; Biomechanics; Instant GRF; Lower Limb Load

Introduction

Golf is a very popular sport around the world, practiced by people of all ages and allowing sport activity in older adults [1]. Therefore, age is considered a main risk factor for Golf related injury and in amateurs players an improved technique could prevent most of the injuries [2]. The golf swing is largely influenced by the feet action [3] which can also influence the movement of the trunk [4]. [5] stated that the contribution of the wrist in achieving maximum club head velocity and control is the result of a culmination of forces originating at the feet. The kinetic chain that begins with the feet, legs and hips movement followed by trunk and shoulders and finally hand and wrists when correctly executed, optimizes kinetic energy to gain maximum club head speed at impact [6]. The principles of mechanics apply to the structure and function of the golfer [7] that undergo the effect of the forces generated during the swing. For the drive, large Ground Reaction Forces (GRF) need to be produced in order to accurately lead the ball to achieve the goal. During the performance of a golf swing, a pattern of ground reac-

tion forces in the lead and trail leg has been observed [5,8-10] Poor swing mechanics reduces the shot accuracy [7,8] and is frequently associated with injury [4,5]. Furthermore, different clubs modify swing kinematics [11]. The magnitude of force generated during the swing and its timing may be critical for the success of this activity. Despite the fact that a number of studies have investigated the vertical ground reaction forces during the golf swing [3,12,13] a limited number have examined the two other planes [3,13] and the timing [10]. Some of the lower limb injury mechanisms may be caused by high torsional and compressive forces during the golf swing [14-16]. Considering that the knee is the most injured site of the lower limb during golf practice, and some of the most frequent knee injuries have been associated with both sagittal and non-sagittal plane biomechanical factors it is of greater importance to study the three plane forces each leg is submitted during the golf swing [17-20]. There is a lack of research in understanding ground reaction forces and its timing in golf swing, for both lead and trail legs, in order to establish its relationship with different club types and injury prevention. Moreover, concerning the average golf player, who represents the majority of golfers and a potential risk for injury, little is studied [5]. The aim of this study was to examine the peak ground reaction forces (F_x, F_y, F_z) generated in each swing phase and their occurrence instant by both lead and trail leg related with the use of three different clubs (7-iron, 4-iron and pitching wedge) during the golf swing. It was hypothesized that ground reaction force patterns in lead (left on a right handed golfer) and trail legs would be dependent of the club used.

Methods

Fifteen right-handed golfers (thirteen males and two female) with average skill level participated in this study. The mean age of the participants was 51,73 ±9,6 years (range 40 to 64), mean height 1.72 ±0.09 m (range 1.5 to 1.8), mean body mass 77.82 ±12.82 Kg (range 50 to 95.8) and mean handicap of 17.3 ± 8.2 (range 12.5 to 26). Participants were instructed to perform eight indoor shots with each of three clubs. An accuracy shot with the pitching wedge (<100m), an intermediate shot (between 100m and 150m) with a 7-iron and a long distance shot with the 4-iron (>150m), in random sequence of four trials per club with the same foot on the force-plate. Golfers used their own clubs, glove and shoes and hit a regular golf ball into a net placed 3m away while standing with one foot on a BERTEC force plate (BERTEC, Colombia, United States of America) covered with an artificial turf golf mat with high shock absorption characteristics. Both feet were analyzed separately. Foot sequence and club order swing were previously randomized. Golfers were instructed to aim at a target placed beyond the net and parallel to the X-axis of the force plate taking into consideration their average distances with the three clubs, making each shot as ecologically valid as possible. Time between each shot was self-paced, but required at least 45 seconds, the processing time for the high-speed video to be written to the hard disk. The participants showed no limitation for golf practice and accepted to complete the investigation protocol. All procedures and objectives of the study were explained to the participants who freely consent to participate. The Research Ethics Committee of the Faculdade de Motricidade Humana-Universidade de Lisboa approved the study. After the explanation of study purposes and collection steps, the subjects filled the Portuguese version of the Survey of musculoskeletal conditions, playing characteristics and warm-up patterns of golfers [21]. Reflective marks were placed [22] for video analysis and synchronization procedures were performed. Before experimental procedures, all subjects performed a warming-up of approximately five minutes and were allowed to perform some experimental swings for a better adaptation to the set-up. Video analysis was used for delimitation of golf swing phases. The golf swing was recorded with five high-speed cameras Basler A602fc (Basler Vision Technologies, Ahrensburg, Germany) at 100 Hz. The cameras were placed anterior, posterior and superior oblique. A sixth camera Casio EX-FH20 (Casio, Tokyo, Japan) recording at 1000 Hz was placed anterior to the ball so that the impact moment was accurately recorded. Two markers were placed on the clubs were placed on the clubs (Horton, Lindsay et al. 2001).

For kinematic analysis a three dimensional SIMI Motion 3D system (SIMI Reality Motion Systems GmbH, Unterschleissheim, Germany) was used. Video and Force data were synchronized to divide the golf swing into five phases: (1) the Backswing – from the address to top of the backswing; (2) the Forward Swing – from the top of the backswing to the horizontal club (early part of Downswing); (3) the Acceleration – from the horizontal club to impact (late part of Downswing); (4) the Early Follow-Through -from the impact to horizontal club; (5) the Late Follow-Through – from the horizontal club to the completion of the swing. Total Swing represented the period from the address to the completion of the swing.

Ground reaction force data during the golf swing were measured using a force platform system (Bertec, Model FP4060-07-1000) at 1000Hz. The Ground Reaction Forces (GRF) data were sampled at 1000 Hz. The GRF acting on each foot were assessed alternatively during four swings with each club in a randomized order. Maximal vertical (F_z), anterior-posterior (F_y), and medial-lateral (F_x) components of GRF data and their occurrence instant were used to analyse the pattern of each swing phase. The values presented are the mean of the four trials for each club performed by the golfer with same foot positioned on the force-plate. A second-order, digital Butterworth low-pass filter was applied to the ground reaction force data, with a cutoff frequency of 5 Hz. GRF values were normalized to the subject mass and expressed in Body Weight Units (BWU). To normalize between subject's duration phase, Instant of Peak GRF is expressed as a percentage of the time in which each phase occurred. The coordinate system of the force plate was such that the positive y-direction pointed

forward the golfer position and positive x-axis is to his left. The z-axis is defined downwards. Data was statistically processed with IBM SPSS Statistics 21.0 (IBM Corporation, New York, USA). Descriptive statistics are presented with mean ± standard error. A one-way repeated measures ANOVA was used to compare clubs. The assumptions of normality and sphericity were tested with Shapiro–Wilk and Mauchly's test, respectively. When the normality assumption was not fulfilled, a Friedman test and non-parametric multiple comparisons were performed. When the sphericity was not verified, the degrees of freedom were corrected with Greenhouse-Geisser test. Pairwise comparisons were performed with Bonferroni test. The significance level was set at $p<0.05$.

Results

Results of Maximal GRF comparison between clubs (pitching wedge, 7-iron and 4-iron) are presented in figure 1. The peak GRF for each component is expressed in units of percent body weight for each participant during each phase, normalized in time phases for the three clubs. (Figure 1) shows plots of the peak GRF components (F_x, F_y, F_z) that occurred along the swing phases for the three clubs (mean and standard error). Presented values correspond to the maximal value occurred during all the period of the phase and not to the value obtained in a previous determined position (Figure 1). The backswing is the phase where greater peak GRF is found for all directions with the three irons and the opposite, is evident during early follow-through. No statistical differences were found for the medial-lateral and vertical peak GRF between clubs on both, lead and trail leg. Although in the anterior-posterior component, statistical differences between clubs were found in the forward swing and the acceleration between irons 4 and 7 ($p=0.006$; $p=0.003$) and for the pitching wedge and 7-iron ($p=0.010$; $p=0.019$) on the trail leg.

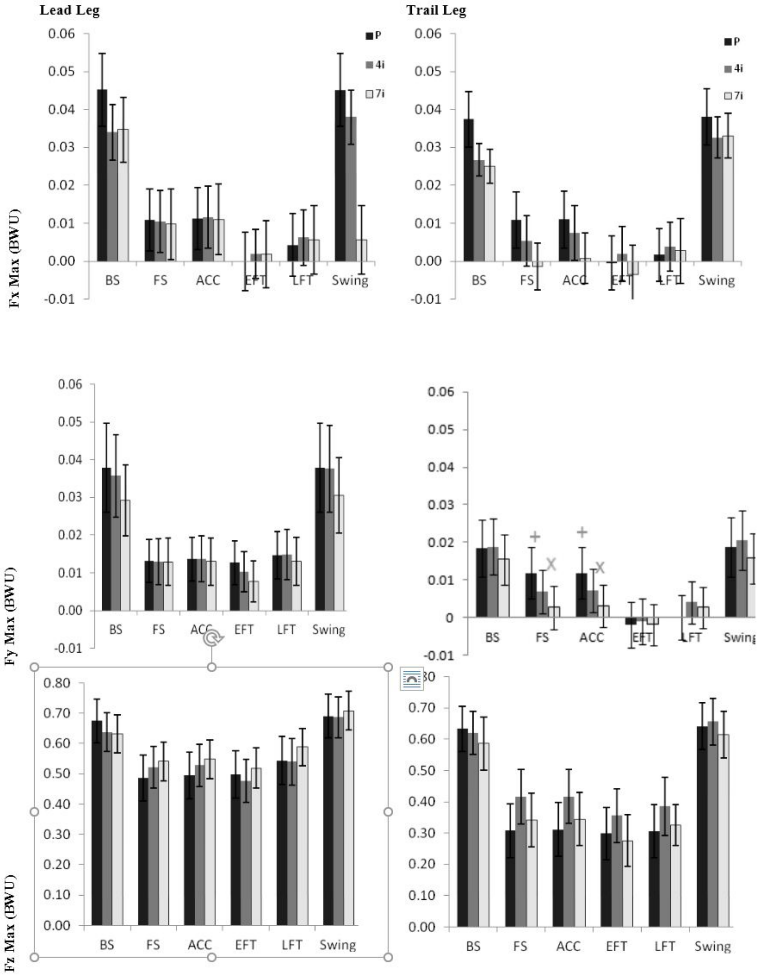

Figure 1: Intensity of peak GRF Mean and Standard error in each phase for the three clubs.

Legend: P - Pitching wedge; 4i - Four iron; 7i-Seven iron; BS-Backswing; FS-Forward Swing; ACC-Acceleration; EFT-Early Follow-Through; LFT-Late Follow-Through; Swing-Complete Swing; *-Significant differences between P & 4i; + -P & 7i; x -4 & 7i. Time is presented as a percentage of the duration of corresponding phase since it is normalized to all subjects. (Figure 2) shows plots of the normalized phase instant where the peak GRF components (F_x, F_y, F_z) occurred along the swing phases (% of time phase mean and standard error) and comparison between clubs (pitching wedge, 7-iron and 4-iron). The peak GRF in the trail leg tends to occur sooner than in the lead leg for all irons. In the lead leg statistical differences were found between the pitching wedge and the 7-iron ($F_{(1.265, 17.71)}$=4.728, p=0.001) in the acceleration phase and between the pitching wedge and the 4-iron ($F_{(2, 28)}$=7.054, p=0.028) during the early follow-through. In the trail leg time differences in time of peak GRF were found on the anterior-posterior component during the backswing between pitching wedge and 4-iron ($F_{(2, 28)}$=4.982, p=0.042). For the medial-lateral peak GRF time differences are found on almost all phases in the trail leg. Between Pitching wedge and 4-iron data show statistical differences during backswing ($F_{(2, 28)}$=3.685, p=0.043), forward-swing ($F_{(2, 28)}$=4.254, p=0.019) and acceleration ($F_{(2, 28)}$=4.602, p=0.015). During the early follow-through pitching wedge and 7-iron show statistical differences ($F_{(2, 28)}$=4.647, p=0.016).

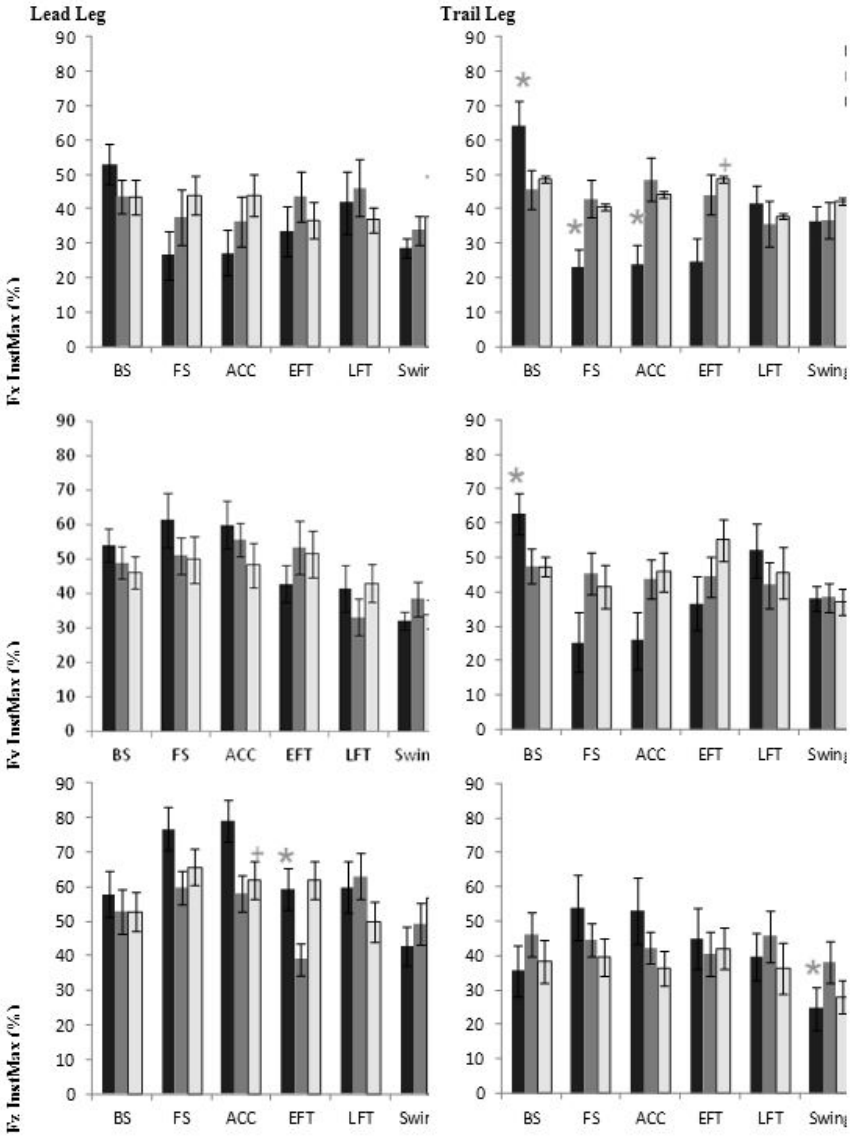

Figure 2: Percentage of time phase Mean and Standard error in each phase for the three clubs.

Legend: P-Pitching wedge; 4i-Four iron; 7i-Seven iron; BS-Backswing; FS-Forward Swing; ACC-Acceleration; EFT-Early Follow-Through; LFT-Late Follow-Through; Swing-Complete Swing.; *-Significant differences between P & 4i; + -P & 7i; x -4 & 7i.

Discussion

This study examined the effect of the use of three clubs for different distance shot (pitching wedge, 7-iron and 4-iron) during the golf swing on the maximal ground reaction forces (F_x, F_y, F_z) generated in each swing phase and their occurrence instant on both, lead and trail leg, for average handicap [12.5; 26] golfers according to European Golf Association proficiency measurement specific system [23]. As the goal is to assess the effect of the club in most prevalent golfers, average players were included in study to avoid the effects of different skilled golfers [3,6,10]. Our results show that statistically significant differences between clubs are found on the time when the peak of the GRF occurs, especially in the trail leg. On the intensity of peak GRF differences are found for the anterior-posterior peak GRF during the downswing. The purpose of the backswing is to position the club head so that the golfer can execute an accurate and powerful downswing [8]. In the present study it is during the backswing that greater peak GRF are found for all clubs. No statistical differences were found for medial-lateral peak GRF on both, lead and trail legs, between the three clubs. During this phase weight is transferred between legs as a result of the rotation of shoulder and pelvis or of the lateral weight shift [8] so that at the top of the backswing weight is prevalent in trail leg [3,7]. Too much shift in any of the directions, medial-lateral or anterior-posterior is often associated with more instability [24] and could result in less control of the movement with a reduction in the accuracy of the swing as the center of golfers' mass will be closer to the edge of the base of support [8]. The anterior-posterior peak GRF on trial leg is almost similar with the three irons although it is slightly higher with four and lower with seven. Regarding the time in the phase where the peak GRF occurs for medial-lateral and anterior-posterior components for all clubs tends to be sooner in the lead leg and slightly after in the trail leg. Though, some differences are found in the trail leg between the pitching wedge and the 4-iron. In both directions pitching wedge peak GRF occurs later in the phase as if with this club a later lateral and anterior-posterior shift is performed. The vertical GRF has an opposite behavior since the peak GRF occurs earlier in the phase for the trail leg and after for the lead leg probably related to the early shift from the back foot to the front foot during the late backswing [6]. Downswing goal is to return the club head to the ball in the best position in order to give the ball the desired trajectory and velocity [8]. During this phase, that includes forward swing and acceleration, peak GRF significant differences are found between pitching wedge and 7-iron and between 4 and 7 irons on the trail leg for the anterior-posterior direction. In both cases, pitching wedge has a greater anterior-posterior peak GRF that happens very early in the phase (25%) compared to the four and seven irons that occur after 40% of the phase (Figure 2). Anterior-posterior significantly different CoP values between clubs have been reported by [25].

On the other hand, the three studied peaks GRF (F_x, F_y, F_z) behavior on the lead leg is very similar for all clubs, the same happening for the time of peak occurrence. In this leg, pitching wedge medial-lateral peak GRF takes place sooner than with the other irons and the opposite occurs in the anterior-posterior peak GRF, where the peak GRF occurs latter on the downswing with the pitching wedge indicating a previous need to shift laterally when using the pitching wedge. Though using different clubs, driver and 5-iron, [3] also reported significantly larger anterior-posterior and lateral forces for the driver as well as did [25] for the anterior posterior and medio-lateral CoP. Driver shows as well greater vertical GRF comparing to the 5-iron. Larger forces in the driver were also reported by [26]. The vertical peak GRF in the present study is increasingly larger from the pitching wedge, 7 and 4 irons in the trail leg but, in the lead leg this pattern changes and a larger vertical peak GRF is recognized with 7-iron although, no significant differences are identified. At the downswing significant differences in time of occurrence of the medial-lateral peak GRF between pitching wedge and 4-iron are observed in the trail leg. When performing the swing with the pitching wedge club the lateral peak GRF takes place sooner than with the 4-iron club (≈23% vs ≈43%). When using the pitching wedge, vertical peak GRF during the swing acceleration phase, occurs significantly later than when the 7-iron is used (79% vs. 62%) indicating that, with the pitching wedge, the maximal vertical force is exerted very close to the moment of the impact with ball. During the follow-through the body and club head are decelerated [27] and must restore from the impact. Lower medial lateral peak GRF are observed at the early follow-through for both legs and all clubs. Lateral shift occurring in this phase is naturally towards the left side since all golfers studied performed a right hand swing. In the trail leg a significant difference between pitching wedge and 7-iron is found with the medial-lateral peak GRF taking place sooner than the 7-iron (25% of the phase duration vs 48%). No other statistical differences are found for magnitude or time between clubs for both legs during the follow-through [3] who used two different clubs, obtained greater lateral shear in lead leg when using the driver in comparison with the five iron. During the complete swing peak anterior-posterior, medial-lateral and vertical GRF showed no differences between clubs for both legs revealing that magnitude in GRF is similar for the three types of clubs used in this study. Despite that, generally lead leg is subjected to greater forces [3,28] with the exception of the medial-lateral peak GRF when swing is performed with 7-iron (Figure 3). Pitching wedge and seven clubs in the medial lateral GRF show statistical differences in the time of the peak in lead leg

which occurs later in the swing with 7-iron (38% of the phase duration *vs* 29%). In the trail leg differences in time of vertical peak GRF are observed between the pitching wedge and the 4-iron with the last taking place later in the swing (38% of the phase duration *vs* 25%).

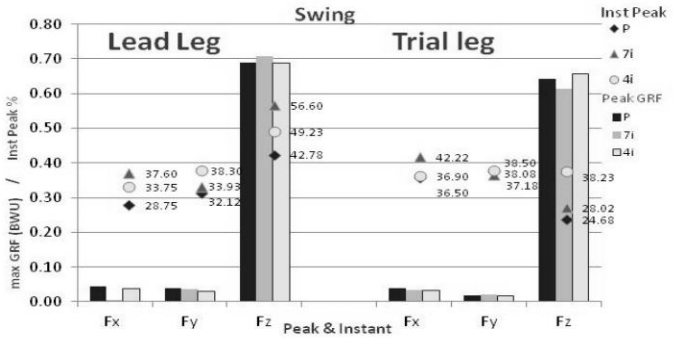

Figure 3: Mean intensity of peak GRF (bars) and instant of peak occurrence (points) during the swing for the three clubs.

Legend: P-Pitching wedge; 4i-Four iron; 7i-Seven iron.

Some limitations can be found in the present study. Foot positioning on the force plate was self-adjusted in each swing to provide a more real movement. This introduces variation to the foot distance to the origin of the force plate coordinate system on the medial-lateral and anterior-posterior GRF components. Although the aim was to study each lower limb individually during the swing a simultaneous data collection of both would allow discussing also weight transfer between foot. Body weight units used report naturally to one limb assessment and not the all weight of the subjects.

Conclusion

The current study described medial-lateral anterior-posterior and vertical maximal GRF and the time in phase when that peak occurred during a golf swing performed by average golfers with three different clubs. Concerning the maximal GRF in both lead and trail leg, our study shows that the swing with the three clubs used is similar. Significant differences occur in the anterior-posterior peak GRF at the downswing just for the trail leg. This study approached the time of peak GRF occurrence normalized for all subjects allowing to better compare different phase durations. Differences in time of peak are mostly found close to the moment of impact, acceleration (pitching wedge and 7-iron) and early follow through for the vertical GRF lead leg. We also found significant differences during the backswing with pitching wedge and 4-iron, for the anterior-posterior GRF trail leg, during the backswing between pitching wedge and 4-iron, during the forward swing and acceleration between pitching wedge and 4-iron and finally in the early follow-through between pitching wedge and 7-iron on medial lateral GRF trail leg. GRF peak and timing knowledge when using different clubs may assist coaches and golfers when deciding strategies to optimize performance as well as in understanding the swing impact in the body and the risk it represents to suffer an injury. Decisions concerning maintaining sport activity or returning to sport must take into account that in anterior-posterior plane the use of clubs for short, intermediate or long distance implies different maximal GRF.

Acknowledgments

The project ‘‘Neuromuscular activity in the golf swing with implications for the practice and in the prevention of overuse injuries’’ was granted by the Portuguese Foundation for Science and Technology- FCT (PTDC/DES/105176/2008). Authors would like to acknowledge Andreas Russ from Simi, Reality Motion Systems GmbH. Sponsors had no involvement in the study.

Conflict of interest

Authors certify that they have no financial affiliation or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed cited in the manuscript. Authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence their work.

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