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Research article

A comparison of golf shoe designs highlights greater ground reaction forces with shorter irons

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Abstract
In an effort to reduce golf turf damage the traditional metal spike golf shoe has been redesigned, but shoe-ground biomechanical evaluations have utilised artificial grass surfaces. Twenty-four golfers wore three different golf shoe traction designs (traditional metal spikes, alternative spikes, and a flat-soled shoe with no additional traction) when performing shots with a driver, 3 iron and 7 iron. Ground action forces were measured beneath the feet by two natural grass covered force platforms. The maximum vertical force recorded at the back foot with the 3 iron and 7 iron was 0.82 BW (body weight) and at the front foot 1.1 BW approximately in both the metal spike and alternative spike golf shoe designs. When using the driver these maximal vertical values were 0.49 BW at the back foot and 0.84 BW at the front foot. Furthermore, as performance of the backswing and then downswing necessitates a change in movement direction the range of force generated during the complete swing was calculated. In the metal spike shoe the vertical force generated at the back foot with both irons was 0.67 BW and at the front foot 0.96 BW with the 3 iron and 0.92 BW with the 7 iron. The back foot vertical force generated with the driver was 0.33 BW and at the front foot 0.83 BW wearing the metal spike shoe. Results indicated the greater force generation with the irons. When using the driver the more horizontal swing plane associated with the longer club reduced vertical forces at the back and front foot. However, the mediolateral force generated across each foot in the metal and alternative spike shoes when using the driver was greater than when the irons were used. The coefficient of friction was 0.62 at the back and front foot whichever shoe was worn or club used.

Key words: Club, friction, grass, handicap, swing, turf .

Introduction

Major technological advances have been made in recent decades in the development of sports equipment. This has been in part because of developments in material technology, but also because of the increased precision and development potential associated with computer aided design. Major changes have also occurred in the design of golf shoes, as due to the increasing popularity of the sport, there have been concerns about damage to golf courses. These changes in shoe design have been precipitated by the damage caused to golf courses and putting greens by the 6 mm or 8 mm metal spikes incorporated in the shoe outer sole which have been fundamental to the traditional golf shoe. These traditional metal spikes compress and grip grass roots, grass or soil, with the likelihood of providing good shoe to ground grip, albeit with possible turf damage. Golf shoes have been developed with outer soles designed to provide additional traction due to the incorporation of specialised raised mouldings and sometimes moulded inserts, but without the potential depth of penetration of the metal spike. Such developments have raised concern over the possibility of a player slipping due to reduced traction at the shoe to ground interface (Slavin and Williams, 1995), and may be a predisposing factor to possible injury as moments about the knee can reach 100 Nm during a normal golf swing (Gatt et al., 1998).

Previous evaluations of the human factors aspects of golf shoe design relating to the golf swing with different types of club have been performed indoors on artificial surfaces (Barrentine et al., 1994; Koenig et al., 1994; Williams and Cavanagh, 1983; Williams and Sih, 1998). These latter studies also evaluated the effect of golf club choice, whether a driver for long distance shots or a shorter iron for closer shots, with Barrentine et al. (1994) considering the influence of experience (indicated by the golfer's handicap). The need for assessments on natural grass surfaces to consider further aspects of alternative spike shoe design was identified by Williams and Sih (1998). Technological developments which have allowed measurements of ground reaction force at the shoe to natural grass turf interface in other sport activities to be better understood (e.g. football and running: Smith et al. 2002; 2004; 2006) are applied in this research to assist in determining fundamental factors in the performance of a golf swing on natural grass turf.

The current study aimed to compare forces generated at the shoe-turf interface when wearing different golf spikes. To assess shoe performance across the range of forces experienced during a round of golf, a range of clubs to represent actual variation produced at the shoe-surface interface was used. In addition as Barrentine et al. (1994) reported different force patterns with playing standard, a spread of golf handicaps were used to assess shoe performance from a representative population. During the golf swing this investigation considered the independent variables shoe (3: metal spike, alternative spike design and flat sole); club (3: driver, 3 iron and 7 iron) and handicap (3: low, medium and high) in relation to the dependent variables maximal vertical force (Fz max), ground action force generation in 3 orthogonal planes Fx, Fy and Fz, and coefficient of friction.

Methods

Twenty-four right-handed male golfers (mean mass 75.3

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SD 9.1 Kg) volunteered for the study. Eight golfers had a low handicap (0-7), eight had a medium (8-14), and eight had a high handicap (15+). All played three times or more a month, with the highest handicap being 26 and the lowest 0. Following an explanation of the proposed research each subject provided written informed consent to participation, in accordance with the conditions of the ethical approval of the research investigation.

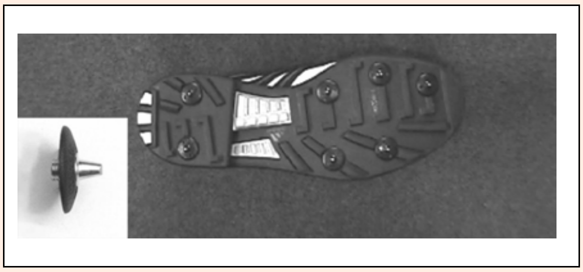


Figure 1. **Adidas golf shoe with 7 metal spikes and a metal spike profile.**

Golfers wore three golf shoe designs with different outer sole configurations and leather uppers. The metal spike shoe (Figure 1) had an ethylene vinyl acetate (EVA) mid-sole, thermoplastic urethane (TPU) Adidas Stripe Tournament outsole and was fitted with 7 Fast Twist™ 8mm metal spikes. The alternative spike shoe (Figure 2) had an EVA mid-sole, TPU outsole (Adidas Z-Traction Tour) fitted with 7 Fast Twist™ alternative Adidas spikes. The flat-soled golf shoe (Figure 3) had an EVA mid-sole, Stilo adapted flat sole and was not fitted with any spikes to provide additional traction. All shoes were new for the research and a range of sizes was available.

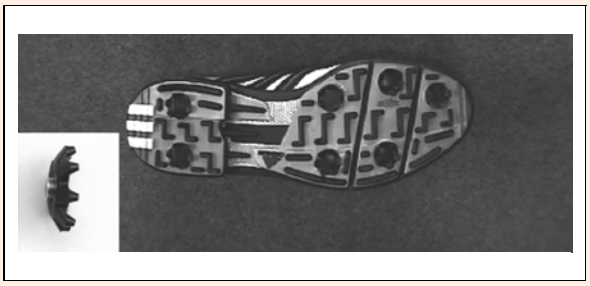


Figure 2. **Adidas golf shoe of alternative spike design with a spike profile.**

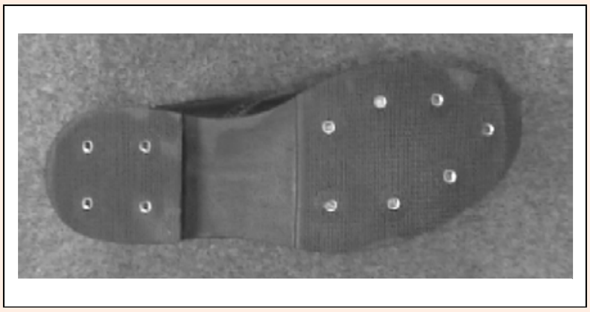


Figure 3. **Golf shoe with flat sole and no additional traction.**

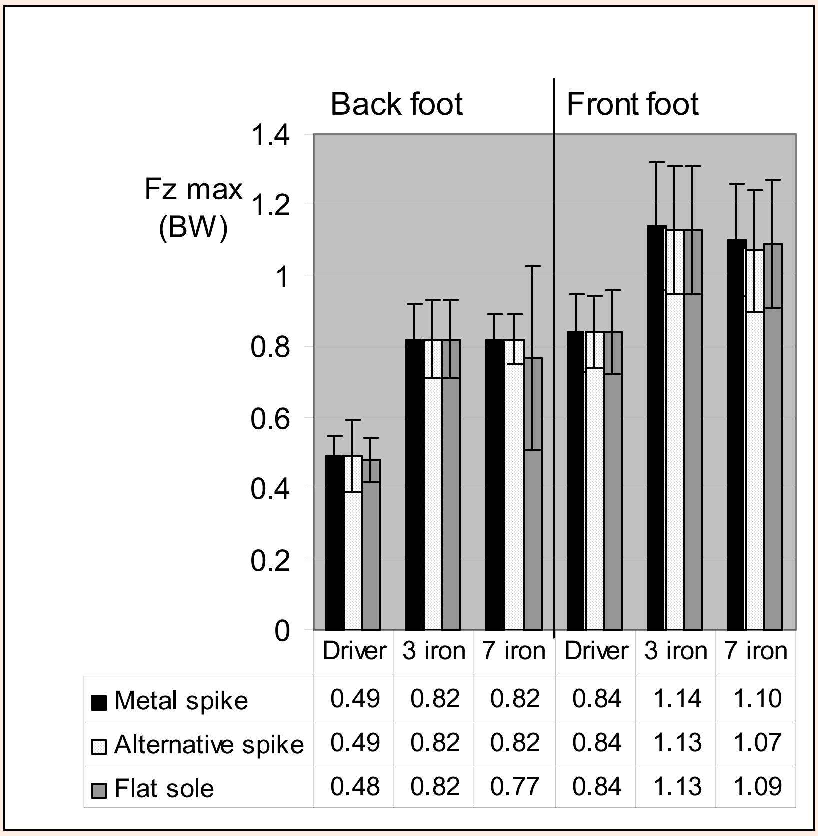
Data collection

Golfers adopted their natural stance to perform a full swing golf shot with each foot on a force platform in an outdoor flat field in good sunny weather. The platforms were embedded in the ground and covered in a natural grass turf surface, similar to that found on a teeing off area on a golf course. The turf (30mm) was attached using clay to smooth plates, which were screwed onto the top of each force platform (Janaway and Dyson, 2000). The Kistler 9851 force platforms' signals were passed to two Kistler 9865 amplifiers, which were connected to an Amplicon 12-bit analogue to digital converter. Kistler BioWare 3.1 software controlled 1000 Hz data sampling and recording. A 200Hz Peak Performance Technologies camera was placed in front of the golfer to capture whole body and club movement and this was recorded on a high speed Panasonic AG-MD830 video recorder. A small instantaneous impact signal delivered to the surface of the force platform prior to the start of each golf swing enabled the 200Hz video recording and force platform systems to be synchronised. The time of ball impact was determined by calculating the number of frames from a force plate synchronization signal to ball impact from the video footage to the nearest 0.005 second. Posterior lower leg and foot movements were also recorded using a 50Hz JVC Compact VHS GR-FX 12EK video camcorder to aid in subsequent analysis.

Once the golfer had become accustomed to the test environment he performed 5 shots using his own driver, 3 iron and 7 iron towards a directional indicator located at 350 m. Golfers were asked to play straight shots (±8° approximately) as they would normally with each club without drawing or fading to simulate the shot landing on the fairway. The outcome of each shot was recorded. Club and shoe order were randomly assigned for each participant. Grass turf moisture level was maintained at level 2 indicated by a Rapitest moisture probe for all testing and the grass covered plates were replaced as soon as any wear became apparent.

Data analysis

The maximal vertical force (Fz max) occurring at the back and front foot during each golf swing was identified in each swing and the mean and SD calculated for all swings. In addition the greatest amount of force generated at the shoe sole to ground interface during each golf swing was determined by identification of the minimum forces occurring during the backswing and maximal forces occurring during the downswing at each foot, which is a similar methodology to that used by Williams and Sih (1998) to compare golf shoe performance. The amount of force generated in each orthogonal plane was normalised to the body weight of each participant. In notational terms foot action anterior forces were positive and posterior foot forces were negative for both feet. In the case of mediolateral action forces for the left (front) foot were medial-negative and lateral-positive and for the right (back) foot medial-positive and lateral-negative. The coefficient of friction was determined from the ratio of vertical to shear forces using the equation $(|Fx| + |Fy|)/ Fz$.



	Driver	3 iron	7 iron	Driver	3 iron	7 iron
■ Metal spike	0.49	0.82	0.82	0.84	1.14	1.10
□ Alternative spike	0.49	0.82	0.82	0.84	1.13	1.07
▩ Flat sole	0.48	0.82	0.77	0.84	1.13	1.09

Figure 4. Mean maximum vertical forces (Fz max) generated at the back and front foot when wearing a traditional metal spike golf shoe, an alternative spike golf shoe and a flat sole shoe with no additional traction.

Straight shots were achieved in 89%, 71% and 46% of cases by the low, medium and high handicap players respectively reflecting the low handicap experienced golfers ability to hit straight shots. Mean and standard deviation force values were calculated for each of the five shots played by each golfer for each club, shoe and handicap condition. Data integrity checks for sphericity using Mauchley's test, homogeneity using a Levene's test and normality using a Kolmogorov-Smirnov test were performed. Data was then analysed using three way ANOVA with repeated measures at a 5% significance level. Significant differences were detected by Post Hoc Tukey HSD test ($p < 0.05$). No handicap group was identified as producing consistent differences between club and shoe conditions. Consequently there was support for the three handicap groups to be amalgamated. Following the same data integrity checks two way ANOVA with repeated measures was then applied to the revised 3 x 3 design (shoe by club). Differences were identified using a Post Hoc Tukey HSD test ($p < 0.05$).

Results

Figure 4 and post hoc analysis revealed the predominant feature that greater maximal vertical forces occurred when using the 3 iron and 7 iron compared to the driver at both the back and front foot ($p < 0.05$). Shoe outer sole design features and golfer's handicap level did not influence maximal forces (Fz max). The coefficient of friction determined for each shoe design was very similar at a value of 0.62 ± 0.03 for both the back and front foot, and this was not influenced by the type of shoe outer sole or club adopted.

The golf swing force action trace (Figure 5) shows the right-handed golfer's weight distributed approximately equally between the front and back foot in the address stance position. The greatest forces are in the vertical (Fz) plane with the back foot vertical force reaching a maximal at the end of the backswing and then a rapid weight transfer shown to the front foot with the vertical force rising to a maximal in the downswing. After ball impact a rapid decrease in force occurs as the follow-through of the club creates upwards force on the golfer. The front foot Fz increases as the club reaches the top of the follow-through. The anterior-posterior (Fy) plane forces show similar patterns with a directional change within the forces of both feet as the backswing-downswing transition occurs and then the associated generation of a couple effect giving hip and shoulder rotation. The front foot medial-lateral (Fx) force shows a medial to lateral transfer with backswing to downswing progression. The back foot medial-lateral trace indicates medial movement as body weight transfers to the front foot at the beginning of the follow-through.

Further analysis indicated that back and front foot vertical force (Fz) generated was also predominantly related to club type with similar trends evident whichever shoe was worn (Table 1). When wearing the traditional metal spike shoe during the performance of the golf swing the front foot Fz generated was significantly greater when

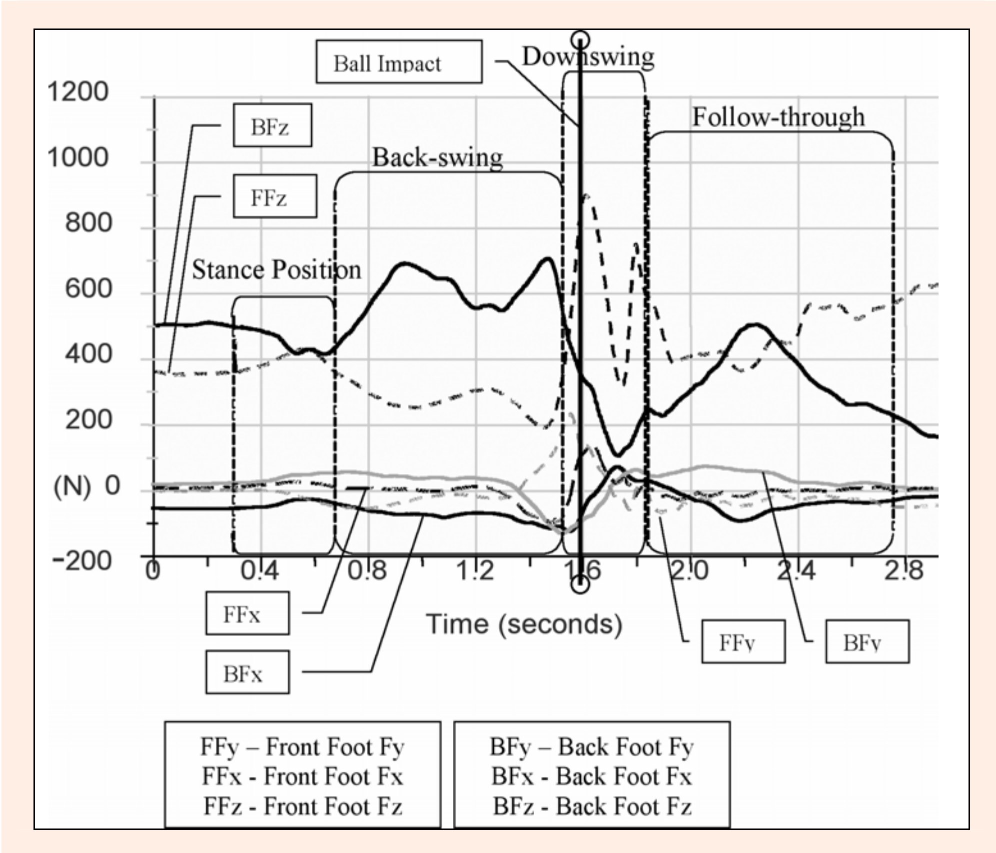


Figure 5. Action force trace identifying the stages of the golf swing with a 3 iron by a high handicap golfer weighing 783N.

the 3 iron or shorter 7 iron were used (0.96 W and 0.92 BW respectively) than when the driver was used at 0.82 BW. Similarly the back foot Fz generated was 0.67 BW for the 3 and 7 iron but less at 0.33 BW when the driver was used. The back and front foot Fy with the driver was significantly less than when the irons were used reflecting a more upright maintained stance during driving. A significant difference was also identified at the front foot in that for each shoe the anterior-posterior Fy range was greater with the 3 iron (0.33-0.34 BW) than the 0.31BW recorded for the short range 7 iron. Consideration of Table 1 indicated that when using the driver and wearing the metal spike and alternative spike shoes the mean Fx forces generated were consistently greater (indicating more sideways force across each foot) than when the 3 iron and the 7 iron were used.

Discussion

Results indicated that modern golf shoe outer sole design features did not significantly influence ground reaction force measures on natural grass turf. The main determinant of force measures was the type of club used.

The force-time profiles generated and recorded in the vertical, mediolateral and anterior-posterior planes show some general similarities in terms of shape and weight transfer to those presented from artificial surface studies by Williams and Cavanagh (1983); Barrentine et al. (1994); Koenig et al. (1994); and Williams and Sih (1998). All the latter identified the greater Fz max at the front foot compared to the back foot in accord with the findings of this research.

In this natural grass turf study the Fz max force at the back and front foot with the driver was significantly less than with the irons. A natural grass turf based study from this laboratory of a more experienced group of 16 golfers (handicaps less than 14) reported Fz max forces at the front foot and back foot respectively of 1.2 BW and 0.77 BW for the 3 iron and for the driver 0.79 BW and 0.49 BW when a different type of alternative spike design golf shoe with less movement specific outer sole mouldings, was worn. The iron data for Fz max and force generation (Fz, Fy, Fx) reported in this research agrees closely with the example given by Koenig et al. (1994). However, Barrentine et al. (1994) reported data showing higher rear foot Fz max around 0.80 BW and front foot Fz max around 1.1 BW for both 5 iron and driver, though in support of the findings of this research further consideration identified that Barrentine et al.'s example driver trace had a much lower back foot Fz max of 0.5 BW and force generation in general agreement with this research.

From detailed consideration of the literature it is evident that the generally reported greater back and front foot forces when using the driver are anecdotal (Dillman and Lange 1994; Hume 2005). Koenig et al. (1994) mentioned that greater forces were generated in the downswing with the driver though no data was provided and there was a similar unsupported statement by Williams and Cavangh (1983). In Barrentine et al. (1994) the difference between the mean Fz max values of the driver and 5 iron was only 8 N at the back foot and 13 N at the front foot.

It is possible that authors in earlier studies on artificial surfaces did not report data for the driver as they

Table 1. Back foot and front foot forces generated by 24 golfers when Fz is vertical, Fy is the anterior-posterior and Fx is mediolateral force. Data are means (±SD).

	Back foot			Front foot		
	Driver	**3 iron**	**7 iron**	**Driver**	**3 iron**	**7 iron**
Traditional metal spike golf shoe						
Fz	.33 (.07) **	.67 (.13)	.67 (.10)	.82 (.11) *	.96 (.16)	.92 (.17)
Fy	.16 (.03) *	.27 (.05)	.26 (.05)	.29 (.04) *	.33 (.04)	.31 (.04)
Fx	.21 (.04) *	.20 (.04)	.19 (.04)	.25 (.03) *	.23 (.03)	.22 (.03)
Alternative spike golf shoe						
Fz	.34 (.12) **	.70 (.15)	.67 (.09)	.83 (.10) *	.94 (.21)	.87 (.30)
Fy	.16 (.03) *	.28 (.05)	.27 (.05)	.30 (.04) *	.34 (.03)	.31 (.04)
Fx	.22 (.05) *	.21 (.05)	.19 (.04)	.26 (.03) *	.22 (.03)	.22 (.03)
Flat sole golf shoe with no additional traction						
Fz	.32 (.11) **	.68 (.13)	.63 (.30)	.83 (.12) *	.96 (.20)	.90 (.19)
Fy	.17 (.03) *	.27 (.05)	.25 (.14)	.30 (.05) *	.33 (.04)	.31 (.04)
Fx	.21 (.05)	.20 (.04)	.19 (.03)	.25 (.03) *	.22 (.03)	.22 (.02)

Significant differences exist between the driver:3 iron and driver:7 iron for all cells (* $p < 0.05$; ** $p \leq 0.001$) with the exception of the shaded back foot Fx.

had reservations about the integrity of the shoe sole interface. Only Barrentine et al. (1994) reported that subjects considered the interface typical and these subjects wore Goodyear welted golf shoes which would not have penetrated the Astroturf surface. Thus it appears that in this research, when the penetration of the outer sole contact surface area protrusions and spike penetration was possible, new data relevant to driver usage and force generation has been gained. The lower vertical forces identified with the driver when compared to the 3 and 7 irons across all handicap groups are considered to be a result of the differing swing planes of the clubs (Coleman, 2007) resulting in a more vertical swing plane for the irons, which was subsequently reflected in the vertical force values. From this research the maintenance of a stable stance seems a key factor whilst swinging the longer length driver, with its resultant inherent ability to create more angular force at the club head to produce a greater ball impact speed. The longer length of the driver results in the adoption of a more upright stance and the need for the golfer to retain stance during the backswing, downswing and follow-through when high centrifugal forces are created. Lindsey et al. (2002) described the existence of a more upright posture with less saggital plane trunk flexion when a driver was in use compared to when a shorter 7 iron was used and positioned closer to the body.

With the driver in this research there was less force generation in the anterior-posterior plane which again indicates the importance of stance to maintain the circling driver club head in position. During the driver's downswing force transfer from the back to the front foot occurs, but as less back foot force is generated in the back swing there is less to transfer to the front foot in the downswing prior to impact. This research investigation has therefore shown that when using irons there is greater force generation in the backswing to the back foot, and then that this allows greater force transfer to the front foot during the downswing to ball impact. In contrast when using the driver the maintenance of stance, with penetration of the natural turf with the golf shoe outer sole mouldings and spikes, is of prime importance to resist the centrifugal forces generated by the swinging club and maintain club head position.

The coefficient of friction measured for all shoes at the sole to turf interface during golf swings with all clubs was 0.62 approximately, and such values do not present a real danger of slip. These data suggest that the golfer may be able to perceive and moderate movement at the feet on natural turf to reduce the risk of slip or golf swing performance impairment. It should be noted, however, that all shots were performed on level ground, and thus do not take into account the undulating nature of a golf course, with the possible increase in slip potential this brings. Further research should consider rotational forces which occur at the shoe to natural turf interface in view of the particularly high centrifugal forces generated with the driver and the observed greater mediolateral force generation at the front foot.

Conclusion

The golf shoe design with additional outer sole mouldings and seven alternative spikes enabled similar force generation to that achieved when the traditional metal spike golf shoe design was worn. During the golf swing the golf shoe design with alternative spikes assessed in terms of maximal force, force generation and coefficient of friction measures would therefore not be expected to carry any increased risk of slipping, or predispose the golfer to injury, compared with the traditional metal spike golf shoe design. This research has highlighted that in an outdoor environment on natural grass turf that the golf swings with the 3 iron and 7 iron were associated with greater forces at the back and front foot than when the longer driver was used.

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Key points

- During the golf swing ground reaction forces at the golf shoe to natural grass turf interface were greater with irons than with the longer driver.
- In the golf swing maximal vertical forces were greater at the front (left) foot in the than at the back foot for a right handed golfer.
- Similar maximum vertical ground reaction forces were recorded with each club when a 8 mm metal spike golf shoe or an alternative spike golf shoe were worn.
- Force generation and coefficients of friction were similar for the alternative spike design and traditional metal seven spike golf shoe on natural grass turf.
- Data collection possible due to application of technical developments to golf from work on other natural turf based sports.

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