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Research article

Kinetic assessment of golf shoe outer sole design features

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Abstract
This study assessed human kinetics in relation to golf shoe outer sole design features during the golf swing using a driver club by measuring both within the shoe, and beneath the shoe at the natural grass interface. Three different shoes were assessed: metal 7-spike shoe, alternative 7-spike shoe, and a flat soled shoe. In-shoe plantar pressure data were recorded using Footscan RS International pressure insoles and sampling at 500 Hz. Simultaneously ground reaction force at the shoe outer sole was measured using 2 natural grass covered Kistler force platforms and 1000 Hz data acquisition. Video recording of the 18 right-handed golfers at 200 Hz was undertaken while the golfer performed 5 golf shots with his own driver in each type of shoe. Front foot (nearest to shot direction) maximum vertical force and torque were greater than at the back foot, and there was no significant difference related to the shoe type. Wearing the metal spike shoe when using a driver was associated with more torque generation at the back foot ($p < 0.05$) than when the flat soled shoe was worn. Within shoe regional pressures differed significantly with golf shoe outer sole design features ($p < 0.05$). Comparison of the metal spike and alternative spike shoe results provided indications of the quality of regional traction on the outer sole. Potential golf shoe outer sole design features and traction were presented in relation to phases of the golf swing movement. Application of two kinetic measurement methods identified that moderated (adapted) muscular control of foot and body movement may be induced by golf shoe outer sole design features. Ground reaction force measures inform comparisons of overall shoe functional performance, and insole pressure measurements inform comparisons of the underfoot conditions induced by specific regions of the golf shoe outer sole.

Key words: Club; driver; grass; ground-reaction-force; insole-pressure; spike.

Introduction

Golf shoe design assessments have principally used ground reaction force measures as an investigative tool. The development of golf shoes with alternative spikes to address concerns over the damage metal spike shoes could cause to the golf course has promoted biomechanical research (Baker, 1999; Hammond and Baker, 2002). Both mechanical prosthetic limb based studies (Slavin and Williams, 1995; Williams and Sih, 1998; Worsfold et al., 2006a) and dynamic golfer ground reaction force studies on artificial and natural turf have informed the golf scientific literature (Barrentine et al., 1994; Koenig et al., 1994; Williams and Cavangh, 1983; Williams and Sih, 1998; Worsfold et al., 2006b; 2006c; 2007; 2008a; 2008b). Frederick (1986) identified that an emerging pattern within the sport shoe literature was that many biomechanical effects result from shoe-induced adjustment of human movement patterns, and Smith et al. (2004) reported ground reaction force kinetics on natural grass differed when wearing soccer training shoes and studded soccer boots during running. Ground reaction force assessments of modern golf shoe designs during performance of the golf swing have also indicated that the human kinetics associated with different golf shoe outer sole traction properties were likely to be worthy of further investigation (Worsfold et al., 2007). Within shoe measures on the underside (plantar) of the foot would provide key information regarding the foot-shoe outer sole interaction. Hennig (1998) identified the importance of such measurements stating that ‘Because footwear modifies the foot to ground interaction considerably, in-shoe pressure measurements are of special interest’ (page 401). Research by Wallace et al. (1994) identified foot pressures and movements of the body and club during the golf swing. Special consideration was given to the load-bearing roles of the feet. Six right-handed male golfers wore spiked and then rubber moulded spike-less golf shoes and played shots off a grass-covered tee-box. Each shoe contained eight piezoelectric film transducers operating at 400 Hz. The study reported that during the downswing when wearing the spiked shoes peak pressures were up to twice those when the spike-less shoes were worn, and it also reported high peak pressures at the first metatarsal heads immediately prior to ball impact. During the last decade in-shoe pressure measurement systems have evolved from a relatively large single sensor placed under the foot location of interest (Wallace et al., 1994) to systems that have hundreds of small pressure sensors distributed over the whole plantar surface of the foot. Such advances in technology, together with improved data processing, offer the possibility of further insights into the human perception and foot-shoe interaction phenomenon.

This study aimed to assess the kinetics of the interaction of the golf shoe outer sole design features with the foot and ground by applying two scientific investigative techniques simultaneously when golf shoes with three different outer sole designs were worn. During golf swing performance with a driver club, the pressures generated on the plantar surface (underside) of each foot were to be measured using pressure measuring insoles, and the forces at the golf shoe outer sole to natural grass interface measured using two natural grass covered force platforms. The outcome of applying these two investigative techniques simultaneously might aid in the understanding of the human kinetics associated with different golf shoe outer sole designs. For performance of shots with a driver when 3 different shoes were worn null hypotheses were investi-

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gated, and thus no significant differences were assumed in vertical force parameters, torque or insole pressure measurement parameters.

Methods

Eighteen right-handed golfers with handicaps in the range of 0 (best) to 19 were recruited to the research study (handicap mean ± SD: 12.4 ± 7.8). All the volunteers played golf three times or more a month and usually wore modern alternative spike golf shoes (but not those used within this research). Subjects provided written informed consent in accordance with the ethical approval by the University research ethics procedures. The male subject group's physical characteristics were age: 29.0 ± 2.1 years; height: 1.80 ± 0.02 m; mass: 81.3 ± 2.7 kg.

Golf shoes

The two spiked shoes had identical leather uppers and ethylene vinyl acetate (EVA) mid-sole. One shoe sole incorporated seven 8 mm high metal spikes in a thermoplastic urethane (TPU) outer sole, one seven 5 mm high alternative spikes in a Z Traction Tour TPU outer sole, and one was a flat soled shoe with leather upper, EVA mid-sole and Stilo flat sole which was not fitted with any spikes or additional traction. Shoes incorporating spikes used the 'Fast Twist Insert System' in order to attach to the shoe outer sole. All shoes were new to avoid the chance of outer sole, spike degradation, or wear characteristics influencing the experimental outcome. Shoes were available in a range of sizes to suit the individual subject. All subjects were given time to gain familiarity with each type of golf shoe through walking and playing golf shots. The golfers informed the experimenters when they felt they were accustomed to the feel of the test shoe, and a time limit was not set by the experimenters.

Data collection procedure

The shoe testing order was randomised across the subject group. Five golf shots with the golfer's own driver were played off a rubber backed 'Astroturf' tee mat, when wearing each shoe type and standing with each foot on a grass covered force platform. New Titelist DT white golf balls were used, with a tee peg if required. Before each golf shot a remote synchronisation switch started data sampling and storage from the two force platforms and also the pressure insole data logger system. During data collection, foot movements and ball impact were captured using a 200 Hz high speed Peak Systems Camera, (Peak Performance Technologies inc. Englewood, Colorado USA) to aid subsequent data analyses.

Ground reaction force measurement

Kistler Bioware v. 3.1 software controlled the data acquisition from two natural grass turf covered 9851 Kistler force platforms, one under the left (front) foot and one under the back (right) foot (Worsfold et al., 2006b; Worsfold et al., 2007). The natural turf (30mm deep) was attached firmly using clay to smooth plates, which were screwed onto the top of each force platform (Janaway and Dyson, 2000; Worsfold et al., 2007; 2008b). The platforms were connected to Kistler 9865 amplifiers set on 2854 N range. For both the front and back foot, vertical maximal force (Fzmax) was normalised to percentage body weight for each participant to allow group statistical analysis. During the golf swing, the club changes direction from backswing to downswing and follow-through, and therefore the amount of force generated (Fz range calculated from the minimum to maximum force (Worsfold et al. 2007) was also analysed. The torque generated (Tz range calculated from maximum to minimum torque values (Worsfold et al., 2008b)) was measured in addition to the maximal torque (Tzmax). It should be noted that the pressure insole system could provide calibrated measures of vertical pressure (only indications of shear force were available within the system), and thus only vertical forces derived from the force platform system were used for shoe comparison purposes in this research. The coefficient of friction measure available in Kistler Bioware software version 3.1 was calculated from the ratio of the resultant shear force to vertical force.

Insole pressure measurement

Footscan RSscan International pressure insoles which had been worn for less than 2 hours were used. The pressure insoles, with small 7 mm and 5 mm polymer sensors (324 sensors for size UK 10 shoe), were fitted inside both the left and right shoes. The shoe insole size was selected by the subject to fit comfortably within the shoe. Once fitted into the shoe the pressure insoles were connected to a Footscan data logger which was attached around the golfer's waist. Data were recorded while the subject sat on a bench (without the feet in contact with the ground) in order to identify that the insole fit within the shoe was correct with no folding, creasing etc. The Footscan pressure insole system software (version 2.33, RSscan International, Belgium) controlled 500 Hz data sampling and recording for a period of 8 seconds. The pressure insole system calculated only dynamic pressure change data during the swing process, and was calibrated to each individual golfer's body weight. Unfortunately sensors in the instep area (R6) of the front foot malfunctioned during testing, but this was not identified until analysis was performed.

Insole pressure data were analysed through both qualitative observational analysis in the form of pictorial displays, and also quantitatively using regional analysis. For observational analysis sixteen specific anatomical markers were selected from those identified in the software; hallux T_1, phalanges, T_2, T_3, T_4, T_5, metatarsal heads M_1, M_2, M_3, M_4, M_5, anterior mid-foot V_1, posterior mid-foot V_2, lateral anterior heel H_1, medial anterior heel H_2, lateral posterior heel H_3 and medial posterior heel H_4 (see Figure 1). Different colours represented ranges of vertical pressure measured by the insole system.

Quantitative pressure analysis utilised dynamic regional analysis which was based on screening the foot from different directions and identified specific foot regions which were adapted to each individual's foot shape and type. The Footscan software automatically detected the footprint as a left or right foot. Markers were then placed on the footprint identifying the foot length and width. The Footscan software then placed a mask on top of the footprint dividing it into nine regions proportional over foot length and width. Pressure data were then analyzed from the nine regions shown in Figure 2 of both the left and right feet. The nine in-shoe regions were all assessed for maximum pressure, average pressure over the swing process, and pressure at ball impact. The latter pressure measure parameters were used in statistical analysis to identify significant differences between the 3 types of shoe.

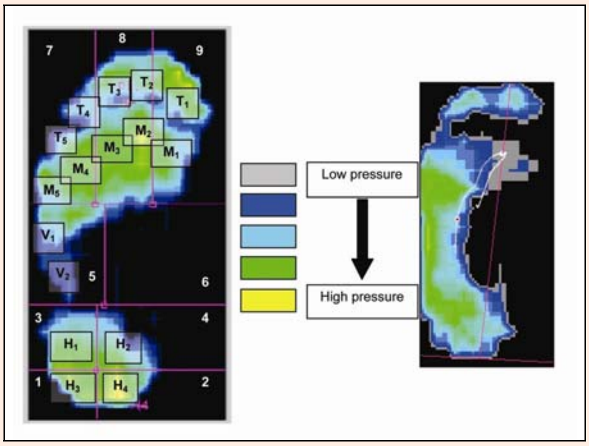

Figure 1. **Pressure range colour scale and example showing available anatomical markers.**

Statistics analysis

Descriptive statistics were calculated for all quantitative ground reaction force and pressure insole system data. Sphericity was assessed using Mauchly's test to identify if variance of differences between conditions were equal. If sphericity was not assumed, Greenhouse-Geisser corrections were used. For the back foot and then for the front foot, ground reaction force and pressure insole data were analysed separately using analysis of variance with repeated measures set at 5% significance level. Significant differences between shoes were detected by post hoc Tukey HSD tests set at 5% significance level.

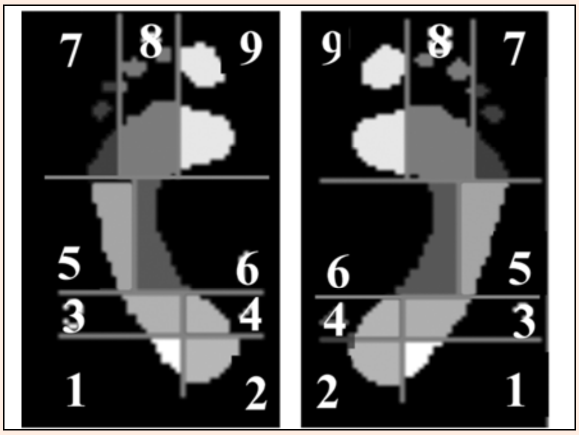

Figure 2. **Example dynamic region analysis identifying the 9 foot regions of the left (front) and right (back) feet .** Note: (1) posterior lateral heel; (2) posterior medial heel; (3) anterior lateral heel; (4) anterior medial heel; (5) lateral mid-foot; (6) medial mid-foot; (7) lateral forefoot; (8) mid forefoot; (9) medial forefoot.

Results

Ground reaction force analysis

For both the front foot and back foot the Fzmax values were similar ($p > 0.05$) for all types of shoe as indicated in Figure 3. Also, more force was generated (range) during the combined backswing and downswing period at the front foot than at the back foot, and forces were similar for all shoes.

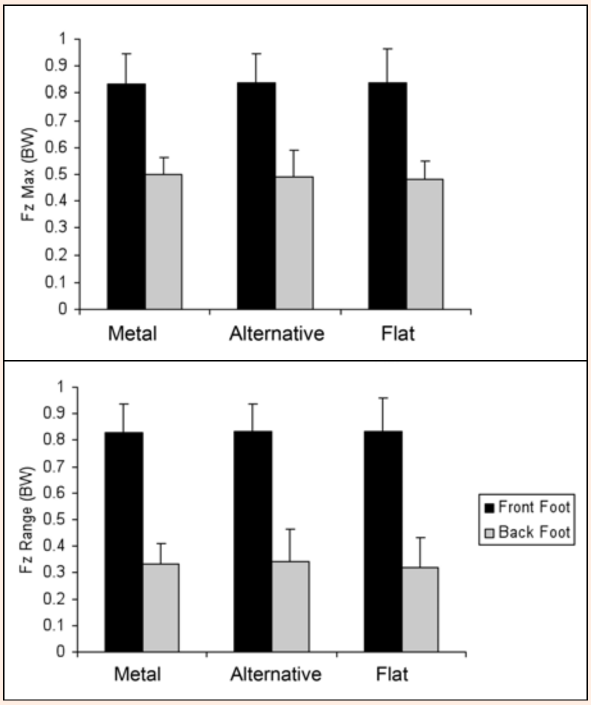

Figure 3. **The mean Fzmax (including baseline of approximately 0.5 BW) and Fz range expressed in terms of body-weight (BW) ±SD measures for the front and back foot when wearing 3 different golf shoes.**

The torque analyses are summarised in Table 1 and indicated that when the metal spike shoe (14.82 ± 1.88 Nm) was worn significantly more torque was generated at the back foot than when the flat soled shoe was worn ($p < 0.05$), and thus the null hypothesis was not supported. The spiked shoes front foot Tzmax was greater than back foot Tzmax (20 Nm and 7 Nm respectively), and more torque was generated (Tz range) at the front foot than at the back foot. Coefficient of friction values measured for the 3 types of shoe when worn on either the front or back foot were similar ($p > 0.05$).

Pressure analysis

Figure 4 illustrates the typical sequential pressures occurring between the foot and shoe when wearing the alternative spike shoe during golf swing performance.

At address the golfer distributed his weight evenly between the feet as shown in figure 4a, with little or no pressure around the medial arch of the right (back) foot and left (front) foot. During the backswing (Figures 4b and c) moderate pressures were recorded from the back foot sole and heel with higher pressure evident at the

Table 1. **Greater torque generation at the back foot in metal spike shoe. Data are means (±SD).**

	Back foot			**Front foot**		
	Tz max (Nm)	**Tz range (Nm)**	**COFxy**	**Tz max (Nm)**	**Tz range (Nm)**	**COFxy**
Metal Spike	7.8 (1.6)	14.8 (1.8) *	.654 (.135)	20.8 (3.7)	38.1 (5.9)	.634 (.097)
Alternative spike	7.2 (1.6)	14.3 (1.9)	.631 (.078)	20.4 (4.3)	38.9 (5.5)	.631 (.085)
Flat sole	7.2 (1.5)	13.2 (2.0) *	.607 (.090)	19.7 (4.0)	39.2 (4.2)	.608 (.061)

* $p < 0.05$.

lateral edge of the back foot and on the heel at the top of the back swing (Figure 4c). Towards the top of the backswing, pressures increased towards maximal as the golfer placed their weight onto the back foot, particularly the heel regions. During the back swing, front foot pressures gradually reduced and maximal pressures occurred under the first and second metatarsals. At the top of the backswing front foot pressure was greatest in the first metatarsal region.

During the initial downswing the club rotated downwards and the focus of back foot pressure was transferred laterally across M_3, M_4, and V_1 until the club reached approximately horizontal. From this position back foot pressure (Figure 4d) decreased rapidly travelling medially across M_4, M_3, M_2, and M_1 with reducing pressure away from the calcaneous (H_1, H_2, H_3, H_4). The downward motion of the club and weight transferring from the back foot to the front foot was associated with increased front foot pressures at the toes (T_1, T_2, T_3, and T_4) and at the lateral foot edge (M_5, V_1, V_2 and H_1). At ball impact (Figure 4e), the back foot pressure decreased from the heel region leaving a pressure focus on the first and second metatarsal (M_1, M_2 and T_1) with the shift of the golfer's body weight more towards the front-forefoot and the heel. The back foot heel began to rise from the ground.

During the follow-through (Figure 4f) pressures under the front foot became generally greater with the exception of the toe regions (T_1, T_2, T_3, T_4). The lateral posterior pressure transfer was a result of the club head travelling up, around and behind the golfer. The highest pressure occurred on the front foot lateral edge and heel, while at the back foot pressures were highest in the first metatarsal region.

Table 2 indicated that significant differences were found between shoes worn on the front foot in the heel regions R1, R2, R3, R4 and in the lateral midfoot region R5 and thus the null hypothesis was not supported. No significant difference between shoes was identified in regions R7, R8, R9 for any of the pressure measurement parameters. Table 3 indicated significant differences in maximal pressures and ball impact pressures between shoes worn on the back foot and thus the null hypothesis was not supported. No significant differences between shoes on the back foot were identified with the average pressure parameter.

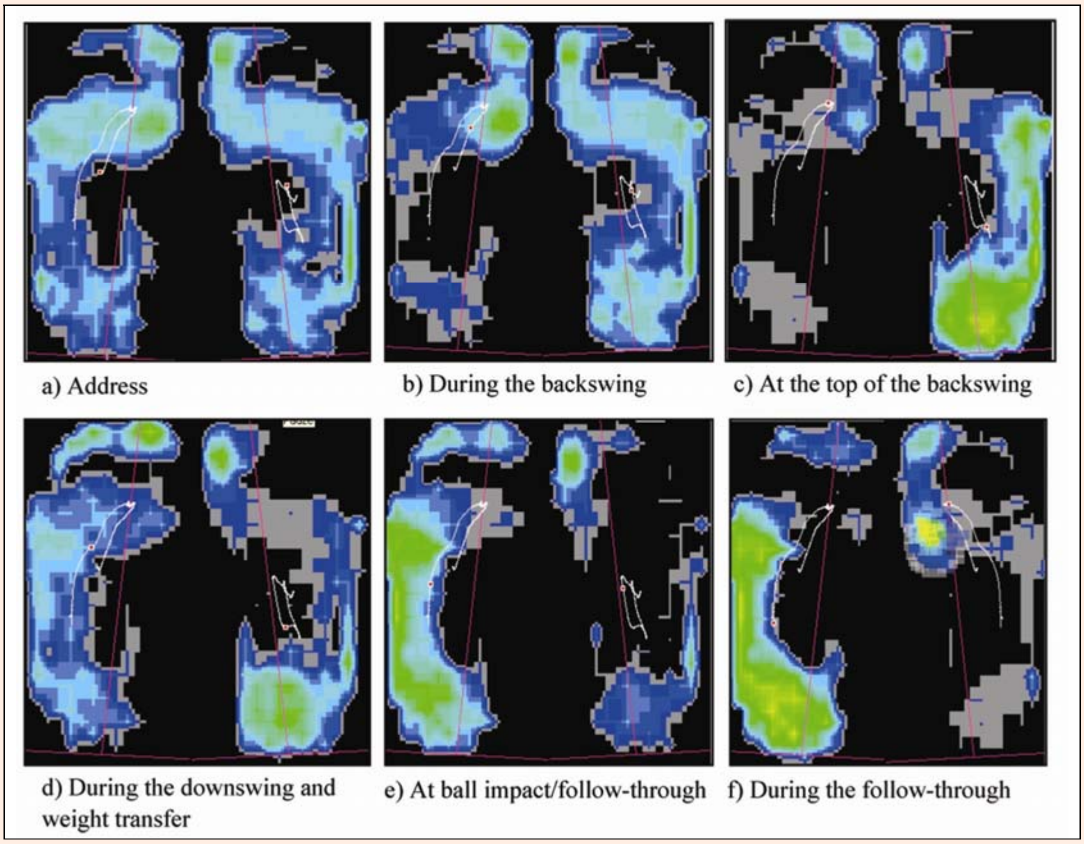
a) Address
b) During the backswing
c) At the top of the backswing
d) During the downswing and weight transfer
e) At ball impact/follow-through
f) During the follow-through

Figure 4. **Example insole pressure scan recorded during the progression of the golf swing movement.**

Table 2. **Front foot maximal and average insole regional pressures (R1-R9) during the golf swing with a driver, and also at ball impact.**

Shoe	Insole regional pressures (kPa)							
	R1	R2	R3	R4	R5	R7	R8	R9
				Maximal				
Metal	93.8	36.2 *	83.7	19.4 *	115.3 * †	97.2	132.6	114.5
Alternative	96.0	33.0	78.8	17.0	87.6 *	96.3	133.8	115.3
Flat	104.7	27.4 *	87.3	13.4 *	102.3 †	102.4	130.0	115.7
				Average				
Metal	41.8 *	16.6 *	34.0 *	10.2 *	44.7	35.2	45.0	48.7
Alternative	43.9	17.3 †	35.8	10.7 †	39.2	35.1	46.6	48.5
Flat	52.7 *	12.8 * †	39.8 *	7.7 * †	42.3	37.6	41.2	47.9
				Ball Impact				
Metal	38.6	9.8*	28.7	5.9 *	29.2	35.36	48.9	49.3
Alternative	37.0	7.7	27.7	4.3	28.2	33.25	47.8	49.1
Flat	35.8	4.52*	26.7	2.7 *	27.7	33.05	44.2	48.4

* and † indicate significant difference between shoes within region $p < 0.05$.

Discussion

Ground reaction force analysis

This research emphasised the different demands on the front and back feet/shoes when using the driver to perform a golf swing in accord with previous research of golf driving on a natural grass turf by Worsfold et al. (2006c; 2007). This asymmetry between the forces at the front foot and back foot have been documented when other golf clubs were used in the performance of the golf swing on artificial turf surfaces by Williams and Cavanagh (1983), Koenig et al. (1994), and Williams and Sih (1998).

Table 1 shows that higher ground action torques were identified at the front foot when compared to the back foot in support of previous findings on natural grass (Worsfold et al., 2006b; 2008b). The findings add further support for asymmetrical shoe sole interface designs with greater support and traction required within the front shoe sole. Torque measures were in accord with values reported previously when different alternative spike golf shoe designs were compared by Worsfold et al. (2006b), suggesting limited foot/shoe alterations were induced by the inclusion of the pressure insoles within the shoes. The metal spike shoe produced a significantly greater Tz range on the back foot when compared to the flat soled shoe, and highlighted the better quality of the traction properties provided by the metal spike shoe sole during rotational movements. The Tz range incorporated the rotational torques of both the backswing and downswing movements during the swing process with maximal values for the back foot occurring at the end of the backswing (Worsfold et al., 2008b). Consideration of the metal spike shoe outer sole design (Figure 5) indicated the presence of protruding mouldings sited to oppose the back foot backswing movement in addition to the metal spikes.

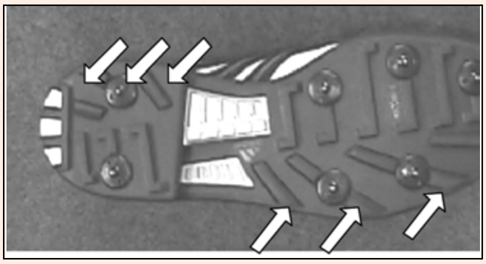

Figure 5. **Metal spike shoe showing direction of imposed force created during the golf swing and the opposing directional sole mouldings which provide additional traction.**

Maximal regional pressure analysis

Table 2 indicated that at the front foot wearing the metal spike shoe resulted in significantly greater pressure change within the lateral mid-foot (R5) region when compared to the alternative spike and flat shoes. This was likely to have arisen because of the increased traction provided by the longer metal spike in this region (Figure 5). This lateral mid-foot region provides support during the torso rotation, and associated rapid weight transfer to

Table 3. **Back foot maximal and average insole regional pressures (R1-R9) during golf swing performance with a driver, and also at ball impact.**

Shoe	Insole regional pressures (kPa)								
	R1	R2	R3	R4	R5	R6	R7	R8	R9
					Maximal				
Metal	39.7	66.0	16.4 *	51.6	7.75	67.8 *	65.4	70.5	78.7
Alternative	38.6	66.6	13.9	49.7	6.0 *	56.3 * †	67.0	77.5 *	77.4
Flat	34.9	66.2	12.2 *	55.3	8.4 *	67.1 †	69.6	66.1 *	82.7
					Average				
Metal	23.5	35.3	11.6	33.6	3.3	46.9	31.7	34.4	43.1
Alternative	23.7	35.6	10.3	33.3	3.3	39.3	33.5	36.6	43.4
Flat	22.1	35.5	7.6	37.0	3.27	45.5	33.4	30.7	45.7
					Ball Impact				
Metal	16.0	21.7 *	3.76	18.7 *	1.79	26.2	27.8	32.4 * † #	42.7
Alternative	15.4	23.2	3.95	21.6	1.92	26.3	28.9	35.2 *	41.1
Flat	15.5	27.5 *	3.18	24.1 *	1.79	25.7	27.2	29.7 † #	43.8

* and † and # indicate significant difference between shoes within region $p < 0.05$.

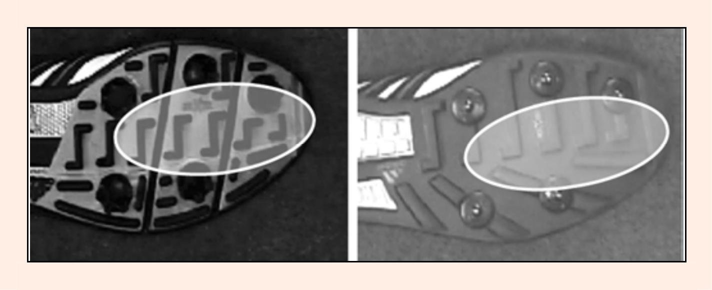

Figure 6. **Region 8 showing specialised Z mouldings on the alternative spike shoe compared with the metal spike shoe.**

the front foot, which starts just before the start of the downswing and continues through to ball impact and the follow-through (Ball and Best, 2007; Worsfold et al. 2008b). Wearing the metal spike shoe also consistently produced significantly higher pressure change underfoot when compared to the flat soled shoe within the front foot heel (R4 and R2) regions. Shoe traction around the heel (R4/R2) is needed to maintain a stable base position for the golfer to rotate around the front leg during the follow-through. The metal spike and directional mouldings on the sole provide traction within this region and prevent the heel slipping anti-clockwise (inwards towards the golfer's right leg) as shown in Figure 5.

Table 3 indicated that wearing the metal spike shoe was associated with greater pressures within the medial back mid-foot (R6) region than the alternative spike shoe, and greater pressure change within the anterior lateral (R3) heel region when compared to the flat soled shoe. These findings highlight the traditional metal spike shoe's ability to provide traction during the clockwise backswing and initial downswing. Wearing the alternative spike shoe resulted in significantly greater pressure change within the mid forefoot (R8) region of the back foot when compared to the flat soled shoe (Table 3). The greater pressure was associated with the additional traction of the alternative spikes and sole protrusions incorporated on the shoe sole (Figure 6). Good traction at the back mid forefoot outer sole is essential to allow the anti-clockwise rotation of the shoe during the follow-through stage of the swing process.

The higher insole pressures reported in Wallace et al.'s (1994) study for metal spike shoe sites were in general agreement with this research, but due to differences in instrumentation and methodology, detailed direct comparison of the latter and current research was not appropriate.

Pressure analysis at ball impact

Table 3 indicated that at the time of ball contact wearing the metal spike shoe and alternative spike shoe was associated with significantly higher back mid forefoot regional pressures (R8) when compared to the flat soled shoe condition, which reflected the maximal pressure findings reported previously. The specialised mid-forefoot mouldings on the outer sole of the alternative spike shoe are shown in Figure 6 and these were associated with greater underfoot pressure production than occurred in the metal spike shoe. At ball contact the back foot must maintain a stable position to allow accurate club head placement.

When the flat soled shoe was worn significantly higher pressures occurred within the back foot medial and lateral mid-foot (R5, R6) regions (Table 3). Wearing the flat-sole shoe produced significantly greater back foot posterior medial heel (R2) and medial anterior heel (R4) pressures at ball impact (Table 3). This anomaly of increased pressure generation in the flat soled shoe was a likely response to the relatively higher traction provided by the sole and heel edges compared to the central outer sole. Video recordings revealed the medial heel edge embedded into the grass during the backswing and downswing.

Average pressure observations

Within the shoe, average pressures were assessed throughout the whole swing process. Front foot pressure analysis (Table 2) identified the metal spike shoe was associated with significantly greater heel (R2, R4) pressure when compared to the flat soled shoe. The alternative spike shoe sole incorporated two medial edge sole traction bars as shown in Figure 7. One bar on the medial edge ran the length of the sole edge (B1) and a second shorter bar (B2) was situated adjacent to an alternative spike. The two bar traction placements in conjunction to the spike placement created sole traction to oppose heel rotational forces.

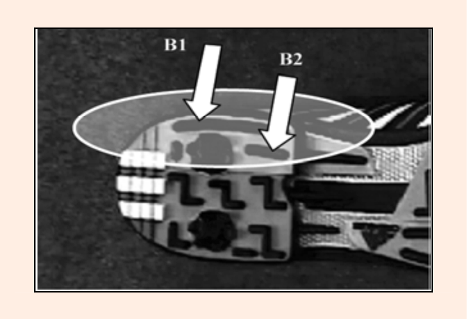

Figure 7. The alternative shoe medial heel traction design.

Consideration of the ground-shoe outer sole linear and rotational force measures and insole pressure measures demonstrated the relationship between key kinetic factors. Firstly, that ground reaction force measures reflect the integrated response of human interaction with functional golf shoe outer sole properties within a performed activity. Comparative measures of linear force and torque can inform overall shoe design, and it is likely by recursive test procedures, also shoe outer sole design features. Secondly, that insole pressure measurement can provide information of more localised design features of the golf shoe outer sole and their

Table 4. Back foot (B1-B11) and front foot (F1-F9) golf shoe outer sole design features illustrated in Figure 8.

B1	Dashed sole edge traction moulding opposing medial/lateral, anterior/posterior forces.
B2	Lateral forefoot traction bars to prevent medial or lateral slipping during the backswing
B3	Lateral edge spikes situated over areas of high in-shoe pressure during the backswing.
B4	Additional lateral mid-foot traction due to high plantar pressures during the backswing.
B5	Mid-foot sole traction creating larger sole surface area.
B6	Heel mouldings opposing anterior and posterior forces. Additional medial spike placements situated over areas of high plantar pressure required during the backswing.
B7	Heel edge raised bar to restrict clockwise rotational forces during the backswing.
B8	Mid-foot sole traction bar supporting and preventing medial slipping.
B9	Traction rail opposing forefoot and heel medial and lateral forces. The curved forefoot rail would facilitate the natural anticlockwise rotation during the follow-through.
B10	Single spike providing medial/lateral, anterior/posterior traction but allowing the natural anticlockwise rotation during the follow-through.
B11	Raised sole oval area to facilitate the natural forefoot rotation anticlockwise rotation during the follow-through. Raised traction mouldings on the oval border maintain forefoot placement during the anticlockwise rotations. The limited forefoot traction facilitates the natural anticlockwise rotations during the follow-through.
F1	Dashed sole edge traction moulding opposing medial/lateral, anterior/posterior forces
F2	Traction rail(s) opposing forefoot and heel medial and lateral forces
F3	Heel edge raised bar to restrict anticlockwise rotational forces during the follow-through.
F4	Heel mouldings opposing anterior and posterior forces. Additional lateral spike placements situated over areas of high plantar pressure during the downswing and follow-through
F5	Additional lateral mid-foot traction due to high plantar pressures during the downswing and follow-though swing stages.
F6	Mid-foot sole traction bar supporting and preventing lateral slipping.
F7	Lateral forefoot traction bars to prevent medial or lateral slipping during the downswing and follow-through
F8	Lateral edge spikes at areas of high pressure during the downswing/follow-through.

Relative efficacy in relation to traction and human moderation of this by muscular control of body/foot movement and position. The insole pressure analysis (particularly maximal pressures) provided more detail than the ground reaction force measures of the efficacy of localised and specific outer sole design features in the metal spike and alternative spike shoes. The golfer can perceive the traction provided by the golf shoe outer sole, not just generally but under specific areas of the foot structure, and thus would act to utilise such traction at the shoe-natural grass interface when appropriate by moderated (adapted) muscular control of the leg-foot complex during a performed action. Sensitive human perception-muscular movement interaction may be used as an indication of outer sole traction requirements. High pressures at the flat soled shoe medial and lateral edges were a response to attempts to improve traction and stability in response to the perceived lack of traction of the flat soled shoe. However it must be acknowledged that the presence of the pressure insole within the shoe would be providing some additional cushioning on the underside of the foot, and thus must by its presence modify human perception of the shoe properties.

Williams and Cavanagh (1983) rationalised that different golf shoe outer sole designs should be considered because of the different demands placed on the back and front foot during the golf swing, and this concept was supported by this research. However, it needs to be borne in mind that the traction provided at the front and back shoe must not be too different since golf play carries the requirement to walk considerable distances (Williams and Cavanagh, 1983), and thus inappropriate traction which differed considerably between the shoes on the two feet could promote asymmetric walking styles.

From this research the adoption of a different golf shoe outer sole design for the front and back foot was supported because of the limb and shoe asymmetry demonstrated within the golf swing movement. Such shoe design modifications would particularly support the dynamic movement of the back foot from the backswing to the follow-through. Functional aspects of sole traction were identified which used traction bar mouldings located on the shoe sole interface positioned to oppose the identified directions of linear and rotational forces. To limit the shoe outer sole slipping upon the grass interface, regions that were subjected to the highest linear forces and torques during the swing could be reinforced with spikes

Table 5. Frontal plane back foot (B1-B4) and front foot (F1-F2) golf shoe outer sole design features illustrated in Figure 9.

B1	Medial forefoot moulding to facilitate forefoot anticlockwise rotation onto the toe during the follow-through. The moulding incorporates traction groves to provided stability during this stage of the swing process.
B2	Wider lateral sole edge providing shoe support during the backswing.
B3	Medial forefoot raised oval moulding allowing the natural anticlockwise rotation of the forefoot during the follow-through. The moulding incorporates a single spike to stabilise the forefoot position. Mouldings surrounding the oval moulding prevent any linear slipping during the rotational movement.
B4	Angled spikes opposing the medial/lateral and anterior/posterior forces. More spikes located on the lateral edge to provided traction during the backswing.
F1	Wider supported lateral sole edge providing shoe support and preventing the shoe buckling during the downswing and follow-through.
F2	Angled spikes opposing the medial/lateral and anterior/posterior forces. More spikes located on the lateral edge to provided traction during the downswing/follow-through

and sole mouldings located at an angle to oppose applied forces as suggested by Williams and Cavanagh (1983). Possibly ‘T’ or ‘X’ shaped mouldings in conjunction with alternative spikes would oppose both lateral and rotational forces created during the swing process. Different levels of traction may be appropriate for golf players according to experience level and handicap. Worsfold et al. (2008b) reported greater torque generation when a driver was used by experienced, low handicap golfers and longer weight transfer times (Worsfold et al. 2008a). Stability, progression and good control with absolute invariance (Bradshaw et al., 2009) during the swing are particularly important to this handicap group as longer distance shot accuracy may be more critical to performance in golf play.

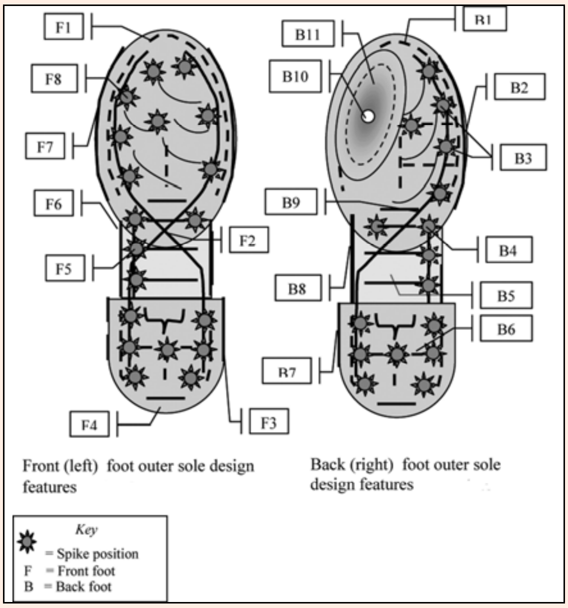

Figure 8. The outer soles of a pair of golf shoes showing movement specific adapted traction for the front and back foot.

Overall consideration of possible golf shoe outer sole design modifications in relation to the traction requirements of the golf swing movement indicated the need for altered outer sole moulding positions and spike locations. Suggestions for such asymmetric shoe design features are summarised in Figure 8 and the accompanying Table 4 denotes the form and purpose of the outer shoe sole traction features. Additional detail of traction features specific to the frontal shoe plane are summarised in Figure 9 and the accompanying Table 5 provides detail of form and function. Utilising the pressure insole measures and moderation of pressure change to indicate dynamic traction requirements for function it is possible to consider the design of localised traction areas on the outer sole of the shoe. Comparison of Tables 3 (back foot) and Table 2 (front foot) reveal that the back foot heel pressures were high in the outer heel regions R1 and R4 compared to the front foot. Figure 4b and Figure 4c indicated high pressures at the top of the backswing. Thus a shoe specifically designed for the back foot should have the traction to oppose the lateral movement in the backswing (Figure 8: B2, B3, B6, B7; Figure 9: B2, B4). This research identified that the incorporation of a mid-sole traction section within both the front and back outer soles would increase the surface area of the sole and thus overall shoe traction, which was also suggested by Williams and Cavanagh (1983) presumably linked to their concept of increasing lateral traction for both feet. Thus additional mouldings to oppose prevalent forces and spikes to improve traction are suggested in the midfoot region (Figure 8: B4, B5, B8 and F5, F6. However at ball impact and during the follow-through good contact of the back foot in the toe region was more important (Figure 4e and Table 3 R8 and R9). At these times the back forefoot must maintain good traction without the risk of slipping as the back foot rotates medially, and possibly the heel raises from the ground. Thus specialised traction for the back forefoot is proposed (Figure 8: B10, B11).

For the front foot good stability especially during the weight transfer from the back foot during the downswing and later follow-through are of prime importance with high pressures recorded and traction needed at the toes and lateral foot edge (Figure 4d and Table 2: R8, R9, R5, R7). Good traction specifically for the front foot shoe could be provided by specialised traction features as illustrated in Figure 8 (F1, F7, F8) and Figure 9 (F1 and F2).

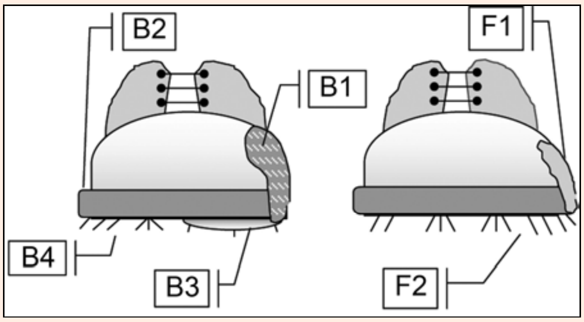

Figure 9. Golf shoe outer sole design features for the back (right) foot and front (left) feet.

Conclusion

Application of two kinetic measurement methods identified that moderated (adapted) muscular control of foot and body movement may be induced by golf shoe outer sole design features. Ground reaction force measures inform comparisons of overall shoe functional performance, and insole pressure measurement inform comparisons of the underfoot conditions induced by localised specific regions of the golf shoe outer sole. Significant differences were identified in torque generation at the back foot and insole pressures at the back and front foot when different golf shoes were worn during golf shot performance with a driver.

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Key points

- Assessments of within golf shoe pressures and beneath shoe forces at the natural grass interface were conducted during golf shots with a driver.
- Application of two kinetic measurement methods simultaneously identified that moderated (adapted) muscular control of the foot and body movement may be induced by golf shoe outer sole localised design features.
- Ground force measures inform overall shoe kinetic functional performance.
- Insole pressure measurement informs of underfoot conditions induced by localised specific regions of the golf outer sole.
- Significant differences in ground-shoe torque generation and insole regional pressures were identified when different golf shoes were worn.

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