The effect of match fatigue in elite badminton players using plantar pressure measurements and the implications to injury mechanisms

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Abstract

The purpose of this study was to investigate the differences in plantar pressure under the lead and trail foot between two lunge tasks to the net in the dominant (LD) and non-dominant (LND) directions, and to explore how fatigue affects the plantar pressure patterns whilst performing movements before and after a competitive match. Peak and mean pressure were measured with the Biofoot-IBV in-shoe system from five repetitions of each task, with sensors positioned under the calcaneus, midfoot and phalanges on the lead and trail foot. Data were collected pre and immediately post playing an official 1st national league competition match. The study was conducted with a sample of thirteen 1st league badminton players. A 2x2 repeated ANOVA found significant differences between the two tasks and between pre and post match (fatigued state). Players also had different foot pressure distributions for the LD and LND tasks, which indicated a difference in loading strategy. In a fatigued state the plantar pressure shifted to the medial aspect of the midfoot in the trail limb, indicating a reduction in control and a higher injury risk during non-dominant lunge tasks.

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Keywords: biomechanics; kinetics; insole-system; competition

Introduction

Badminton is reported to be the fastest racket sport when considering ball velocity (Jaitner & Gawin, 2007). Its popularity has grown since its inclusion at the '92 Olympic Games in Spain and the use of a new scoring system in 2006 (Chen, Wu, & Chen, 2011), with up to 200 million players worldwide (Kwan, Cheng, Tang, & Rasmussen, 2010). The sport is characterised by short duration high intensity actions placing a high demand on the anaerobic system (Cabello & González-Badillo, 2003). The sport requires good footwork including; rapid turning, pivoting, jumps, lunges and running; in order for players to reach and hit the shuttlecock and to return to a defensive position in the centre of the court (Gibbs, 1988) which has not been analysed previously. There is a lack of quantification the court movements on the literature in a real competition context.

It has previously been reported that up to 70% of injuries are to the lower limbs, with the remaining 30% being due to loss of balance, slips and falls, landing or collisions with other players (Hensley & Paup, 1979; Krøner et al., 1990; Reeves, Hume, Gianotti, Wilson, & Ikeda, 2015). However, as in other racquet and field sports, badminton cannot be appropriately simulated in the laboratory setting (Faude et al., 2007). The majority of match based studies on badminton performance have focussed on notational performance analysis (Abián, Castanedo, Feng, Sampedro, & Abián-Vicén, 2014; Barreira, Chiminazzo, & Fernandes, 2016), game characteristics (Phomsoupha & Laffaye, 2014), or physiological and ground reaction force data (Chen et al., 2011; Ramos, Del Castillo, Polo, Ramón, & Bosch, 2016).

Players footwork during lunge movements has been previously reported (Kuntze, Mansfield, & Sellers, 2010), however the nature of on court movements had not been considered until recently (Valldecabres, de Benito, Casal, & Pablos, 2017). Valldecabres et al. (2017) divided the court into 12 parts, and described 3 different on court footwork movements which were commonly used to hit the shuttle, these were; diagonal, transverse and longitudinal, of which more than 50% were diagonal court movements.

Several studies have investigated injuries during badminton (Hensley & Paup, 1979; Jørgensen & Winge, 1990), with a higher risk of injury during competitions when compared to training sessions (Jørgensen & Winge, 1990). Of these injuries, 43% have been reported as patellar tendinopathy (Shariff, George, & Ramlan, 2009), which is considered a common injury in sports with jumps, cutting manoeuvres and explosive running tasks (Tibesku & Pässler, 2005). The clinical injury risk incidence has also been analysed and found that 26% of players had previous symptoms before getting injured (Fahlström, Björnstig, & Lorentzon, 1998) being overuse sprains and strains the most musculoskeletal common injury (Goh, Mokhtar, & Mohaman, 2013; Hensley & Paup, 1979; Shariff, George, & Ramlan, 2009). Lower limb dominance is an important consideration during sports tasks, and has been identified as a factor associated with potential Anterior Cruciate Ligament injury risk (Negrete, Schick, & Cooper, 2007). However, lower limb dominance seems to be more related to specific movement tasks which require different side to side movements (Peters, 1988), such as one side being used for more postural stabilization (Velotta, Weyer, Ramirez, & Winstead, 2011). This was highlighted by Sinsurin, Vachalathiti, Srisangboriboon & Richards (2018) who found better coordination during multi-direction jump landings on the non-dominant limb. The literature also suggests differences in the injury incidence between the dominant and non-dominant limbs for many sports, which has been attributed to side to side differences in loading as a result of differences in movement strategies between the sides (Vauhnik et al., 2008). For example, Kimura et al. (2010) reported that the knee on the lead limb side was the most commonly injured in badminton players, in particular during cutting and side-step movements to the racket-hand side. In addition, Krajnc et al. (2010) showed that the non-dominant leg, defined as the one that is not used to kick a ball, suffered more knee injuries than the dominant leg in soccer players, with players requiring more operations with greater pain or discomfort after surgery on the non-dominant limb. Side to side differences have also been identified in badminton (Kimura et al., 2010), with a higher number of injuries seen on the non-dominant leg.

The incidence of lower limb injuries has also been shown to be linked to fatigue, which has been associated with a decrease in neuromuscular control, impaired kinesthesis and proprioception of joints, and a diminishing maximum voluntary strength (Dickin & Doan, 2008; Rozzi, Yuktanandana, & Pincivero, 2000; Saragiotto, Di Pierro, & Lopes, 2014; Whyte, Burke, White, & Moran, 2015). Links between fatigue and exercise have been investigated previously, however the exact definition of fatigue varies between studies (López-Calbet & Dorado-García, 2006). Fatigue may be considered as multidimensional or multifactorial (Hunter & Smith, 2007; Millet et al., 2011), which may be characterised by the decrease of the capacity or ability to generate force or muscle power. This originates from physiological, mechanical and psychological modifications (Stirling, Von Tscharner, Fletcher, & Nigg, 2012) and a reduction of performance, which has been described as a conservative response to maintain tissue integrity (Millet et al., 2011). Previous work considering fatigue in badminton players has shown that dynamic postural control and the quality of athletes' performance is lower in a post fatigue state (Sarshin, Mohammadi, Shahrabad, & Sedighi, 2011). Players' perceived fatigue may be assessed using the rating of perceived exertion scale (Borg, 1982a), which has been shown to be valid for the assessment of exercise intensity during badminton matches (Fernández, de la Aleja, Moya, Cabello, & Méndez, 2013).

Previous investigations into sports related tasks have shown plantar pressure is an important method of quantifying the magnitude and location of the force applied beneath the foot, which may be measured using in shoe pressure systems (Falda-Buscaiot, Hintzy, Rougier, Lacouture, & Coulmy, 2017; Navarro, Zahonero, Huertas, Vera, & Barrios, 2012). Fu, Liu & Wei (2009) studied badminton lunge tasks, and found the maximum peak pressure was distributed under the forefoot with lower pressures under the midfoot. Conversely, Hu, Li, Hong & Wang (2015) found lower pressures under the forefoot with the maximum pressure under the heel, indicating either differences in movement strategy or test protocol. Changes in distribution of foot pressure, for example midfoot loading, has been associated with foot pronation and patellofemoral pain (Thijs, Van Tiggelen, Roosen, De Clercq, & Witvrouw, 2007; Powers, 2003). In addition, the static assessment of foot posture using the Foot Posture Index (Redmond, Crosbie, & Ouvrier, 2006) has been shown to be important in the prediction of clinical subgroups in people with patellofemoral pain (Selfe et al., 2016). Therefore, the use of foot pressure may allow an assessment of changes in loading strategy and dynamic postural control on the trail and lead limbs which could be performed in the competition arena. This could be useful in the assessment of training and injury prevention, or when considering when to return to sport after an injury.

The aims of the present study were to investigate the differences in plantar pressure under the trail and lead foot between two lunge tasks to the net, and to explore how fatigue affects the plantar pressure patterns whilst performing movements before and after a competitive match. It was hypothesised that lunge tasks to the dominant side (LD) and lunge tasks to the non-dominant side (LND) would show different foot loading strategies and that players would show changes in plantar pressure patterns in a fatigue state.

Methods

Participants

The inclusion criteria for both genders were; players in the 1st Spanish badminton league who played at least 3 times a week, with no injuries to the upper and lower limbs in the previous 6 months. In addition, all participants had no history of surgery or traumatic injury to the lower extremities or lower back, and no history of medical conditions that limit physical activity. Exclusion criteria included; presence of neuromuscular or vestibular conditions, visual impairment or back pain.

Thirteen right-handed badminton players (5 males and 8 females) participated in the study. Anthropometric measurements of height and weight were recorded; age 25.93 ± 10.05 years and bodyweight 64.30 ± 8.66 kg. Hand laterality was assess using a previously validated questionnaire (Chapman & Chapman, 1987), which includes questions such as *which hand do you use to throw a ball* or *which foot do you use to kick a ball,* which has been used in previous studies (Brophy, Silvers, Gonzales, & Mandelbaum, 2010; English, Brannock, Chik, Eastwood, & Uhl, 2006). In addition, Foot Posture Index (FPI), a clinical tool that measures foot type between +12 (pronated) and -12 (supinated) was recorded (Redmond, Crosbie, & Ouvrier, 2006). This study was approved by the Valencia Catholic University San Vicente Mártir Ethics Committee and all data collection conformed to the Declaration of Helsinki. Volunteers gave written informed consent and parental consent for the four participants who were minors was obtained prior to participation.

Equipment

In shoe plantar pressure data were recorded using the Biofoot-IBV in-shoe system (Valencia, Spain), which consists of 64 sensors of 0.5mm thickness and 5mm diameter and has been previously validated and used to assess sports tasks (Martínez, Hoyos, Brizuela, Ferrús, & González, 1988; Marhuenda, Fuentes, Costa, Ferrús, & González, 2011). Not normalised peak and mean pressure data were used according to previous studies (Patrick, & Donovan, 2018; Taylor, Nguyen, Griffin, & Ford, 2018). In addition, the regions of interest where normalised to foot size following Oliveira, Sousa, Santos, & Tavares (2012) with values for foot shape proposed by Hu et al. (2015).

Procedure

In order to familiarise the players, submaximal lunge tasks were performed to the right and left sides, LD and LND respectively for a right-handed player (figure 1). During the lunge, the role of the non-stepping limb is to support the bodyweight during the forward movement of the lead limb (Hofmann, Holyoak, & Juris, 2017) and reaches a maximum knee flexion during landing, this is followed by a movement backwards in order to recover to the initial starting position (Kuntze et al., 2010). The lunge tasks were performed at 45° to the net in the defensive position (Gibbs, 1988), and were defined as controlled movements of the knee such that the knee did not move in front of the ankle joint. The most natural start position for the lunge task was identified for each player in order to hit a shuttlecock that was hung using a fine thread at a height of 165cm, 10 cm from the net (figure 2). Prior to data collection, a standardised 10 minute warm-up was performed, which included active stretching of the quadriceps and hamstring muscles (Lam et al., 2017), specifically this involved five repetitions of 30 seconds per muscle; and a familiarization period which involved the participants performing as many repetitions of the lunge tasks as they needed to feel comfortable (Gribble, Hertel, & Plisky, 2012).

[Figures 1 and 2 near here]

Pressure sensors were then placed in both shoes by fixing them to the insole to avoid them moving within the shoe. Changes in foot pressure data were recorded at a sampling frequency of 265Hz. en directions. Each lunge task trial consisted of a lunge to the net, hitting the shuttlecock with a top-spin shot and moving back to the start position as fast as possible to simulate a match shot. Approximately 5 minutes after participants had played a competition match the lunge tests were repeated. In addition, the level of match intensity was assessed using the Rated Perceived Exertion (RPE) Scale (Borg, 1982a). This determined the perceived intensity of the exercise, from 0 (nothing at all) to 10 (very, very heavy) (Borg, 1982b).

The plantar surface of the foot was divided into 9 areas previously reported by Navarro et al. (2012) (figure 3), these included; hallux, 2nd and 3rd phalanges and 4th and 5th phalanges, 1st metatarsal, 2nd and 3rd metatarsals and 4th and 5th metatarsals, medial midfoot and lateral midfoot, and calcaneus. The peak pressure (PP) and average pressure (PMEAN) of the whole foot were recorded and an average value from 5 repetitions was found for each parameter for each movement direction for both the lead and trail feet.

[Figure 3 near here]

Statistical Analysis

Based on previous papers by Lam et al. (2017) and Park et al. (2017) and an alpha level of 0.05 and an 80% power, a sample size of at least 13 was found to be required to explore the differences between sides and fatigue state. The data were checked for normality using the Shapiro-Wilk test and found to be suitable for parametric testing. In addition, partial eta squared (ηp^2) was computed to determine the effect size which was interpreted as small 0.1, medium 0.3, and large 0.5. Statistical analysis was performed with SPSS 21.0 (IBM, Armonk, NT, USA).

A 2x2 repeated ANOVA found significant differences between the two tasks and between pre and post match (fatigued state).

Results

The players had a mean RPE after playing the competition match of 7.54 (SD 2.10), with a range of perception of fatigue between strong and extremely strong. The average match length was 26 minutes 29 seconds with a standard deviation of 8 minutes and 9 seconds. The FPI showed mean values of 1.17 (SD 1.79) for the lead foot and 1.50 (SD 1.72) for the trail foot, which corresponds to a neutral foot posture (Redmond, Crosbie, & Ouvrier, 2006). All players were at a similar level, and were all Spanish 1st league competitors and were playing for the Championship.

Significant main effects were seen between pre and post fatigue on the lead foot. These revealed significant differences under the 4th and 5th Phalangeal areas between pre and post fatigue for the peak and mean pressure ($p=0.035$, $\eta p^2=0.32$; $p=0.031$, $\eta p^2=0.33$) respectively, with lower values in a fatigue state. In addition, a reduction of lead foot peak pressure under the lateral side was seen with a corresponding increase in peak pressure under the medial side of the midfoot, although the latter was not statistically significant (table 1). A significant interaction was seen between the factors of lunge task and fatigue state under the 2nd and 3rd Metatarsals ($p=0.011$, $\eta p^2=0.43$). Further post hoc analysis explored differences between pre and post fatigue for each lunge task separately, which showed an increase in peak pressure post fatigue for the LD task and a decrease with the LND task (table 1). In addition, the calcaneus mean pressure for the lead foot in the LD task was lower than the LND task ($p=0.032$, $\eta p^2=0.33$) (Table 2), indicating a different strategy during landing between lunge tasks.

[Tables 1 and 2 near here]

Significant differences were also seen under the 1st Metatarsal on the trail foot pre and post fatigue for the peak and mean pressure ($p=0.048$, $\eta p^2=0.29$; $p=0.046$, $\eta p^2=0.29$) respectively, with a decrease in pressure post fatigue in both LD and LND tasks, and a corresponding significant increase in medial midfoot pressure. Finally, the medial midfoot showed an increase in peak and mean pressure post fatigue for both the LD and LND tasks ($p=0.022$, $\eta p^2=0.37$; $p=0.046$, $\eta p^2=0.29$) respectively (Tables 3 and 4), which would imply a shift in pressure to the medial midfoot as the players fatigue.

Significant main effects were seen between LD and LND tasks. These revealed differences in the peak and mean pressure under the Hallux ($p=0.008$, $\eta p^2=0.45$; $p=0.020$, $\eta p^2=0.38$) respectively. This showed the Hallux pressure was lower in the LND task than the LD task in the trail foot (tables 3 and 4), with a corresponding lower pressure in the LND task versus the LD task for the peak and mean pressure under the 4th and 5th Phalangeal areas ($p=0.026$, $\eta p^2=0.35$; $p=0.017$, $\eta p^2=0.39$) respectively (tables 3 and 4). In addition, significant differences were found between the LD and LND tasks in the mean pressure under the Hallux ($p=0.038$, $\eta p^2=0.31$) (table 4). Furthermore, a significant interaction was also seen for the peak pressure under the 2nd and 3rd Phalangeal areas in the trail foot between lunge task and fatigue state ($p=0.017$, $\eta p^2=0.39$), with a greater pressure being seen during the LD task, although this was not significant (Table 3). A further post hoc analysis revealed a significant difference in peak pressure between pre and post fatigue in the LD task on the trail foot only ($p=0.045$, $\eta p^2=0.30$).

[Tables 3 and 4 near here]

Discussion and Implications

A fatigue state has been shown to reduce athletes' performance and can lead to poor joint control (Chang, 2015) and a decrease in dynamic postural control in badminton players (Sarshin et al., 2011). Furthermore, the biomechanics and movement patterns have been shown to be modified as a result of fatigue (Chang, 2015), which could lead to a subsequent increase in injury rate. Footwork manoeuvres are therefore extremely important for badminton players and the consideration of how landing strategies change on the different limbs after fatigue may help us to understand injury mechanisms (Phomsoupha & Laffaye, 2014). Diagonal lunge tasks have been previously shown to account for approximately 50% of on court manoeuvres in both male and female players (Valldecabres et al., 2017). This movement is required to allow the players to move to hit the shuttlecock, and the speed and reaction time are important to allow the player to recover a defensive court position to be ready for the next shot (Gibbs, 1988). Therefore, the aim of this study was to explore differences in foot contact pressures under the lead and trail foot during two badminton specific lunge tasks to the net, and to determine how plantar pressure patterns change as the players' fatigue.

The Foot Posture Index has been used to determine foot type in athletes in different sports including; basketball, handball and running (Martínez-Nova et al., 2014). Our results show a neutral foot type across the participants. However, when athletes fatigue, their foot posture tends to move towards a more pronated position (Cowley & Marsden, 2013), which could be an indicator of arch collapse leading to an increase of plantar pressure under the medial midfoot. Jørgensen & Winge (1990) reported that more than 30% of lower limb injuries are to the foot or ankle joint. This could be related to a flattening of the arch with a more pronated foot position (Lange, Chipchase, & Evans, 2004), leading to associated injuries (Barton, Bonanno, Levinger, & Menz, 2010; Beeson, Phillips, Corr,

& Ribbans, 2009; Graham, Jawrani, & Goel, 2011; Raissi, Cherati, Mansoori, & Razi, 2009).

This study found an increase in pressure under the medial aspect of the lead foot, indicating a more pronated foot or a collapse of the arch post fatigue with the adoption of a flatter foot posture, which is in line with previous findings (Wei, Liu, Tian, & Fu, 2009). This would arguably increase the pronation and pronation velocity which have been previously identified as key factors in patellofemoral pain and patellar tendinopathy in runners (Powers, 2003; Thijs et al., 2007), the latter of which has been identified as an issue in 43% of badminton players (Shariff et al., 2009). In addition, the side-to-side differences found may help to explain the higher injury rates which have been reported on the non-dominant leg (Krajnc et al., 2010). One consideration to help mitigate this effect is the use of foot orthoses. These could be used to directly manage foot posture by supporting the arch and therefore decreasing the pronation and pronation velocity when athletes are in a fatigued state. This in turn may reduce the incidence of patellar tendinopathy (Mündermann, Nigg, Humble, & Stefanyshyn, 2003). However, more research is needed to explore the use of foot orthotics in badminton players, and their effect on potential injury mechanisms when athletes are in a fatigued state.

When comparing LD and LND tasks on lead foot, there are differences in pressure under the Hallux, a lower pressure under the 4th and 5th Phalangeal areas and a lower calcaneus mean pressure, which indicates a possible change in strategy during landing as Vauhnik et al. (2008) reported in other court sports. Lower pressure on the forefoot and lateral areas could be due to the involvement of pelvic rotation which has been reported by players who find dominant side movements easier than non-dominant side ones (Bazipoor, Shojaeddin, Shahhoseini, & Abdollahi, 2017). Further exploration of such compensations was beyond the scope of this current study

After fatigue, a significant decrease in mean pressure under the Hallux and 1st Metatarsal areas and a significant increase under medial midfoot were seen in both LD and LND tasks. This would support the shift in pressure to the medial midfoot and collapse of the arch when players reach a fatigued state which is in agreement with previous literature (Weist, Eils, & Rosenbaum, 2004), and supports that changes in plantar pressure distribution occur due to fatigue (Bisiaux & Moretto, 2008). This has implications to the foot movement used to recover the initial position in the centre of the court with cutting and pivoting creating a higher tibia rotation torque (Oh, Kreinbrink, Wojtys, & Ashton-Miller, 2012) which has been linked with patella mal-alignment and an increased risk of patellofemoral pain (Sinclair & Dillon, 2016).

During both LND and LD lunge tasks the Hallux, 4th and 5th Metatarsals all showed lower mean and peak pressure on the trail limb (tables 3 and 4). The explanation for this could be different hip movement strategies when lunging towards the net, with movement into hip external rotation during the LD task, and a move into hip internal rotation when performing the LND task which has been previously reported by Valldecabres, de Benito, Littler & Richards (2018). In addition, the trail limb is in contact with the ground for longer and is responsible for the eccentric control as the person lunges forwards, which is similar to findings reported during fencing, where the trail/rear limb demonstrated lower pressures (Trautmann, Martinelli, & Rosenbaum, 2011).

This current study is the first to explore the plantar pressure patterns in the lead and trail foot. Previously published work by Hu et al. (2015) on plantar pressures during badminton movements has only taken into account the dominant/lead limb during lunge tasks to the net. This work offers a contribution to knowledge on the changes in movement strategies due to fatigue within a competition environment in elite players. However, more work is required to assess how fatigue affects pronation and pronation velocity, knee joint stability and compensations in pelvic rotation in badminton players.

This study was not without its limitations which included a large standard deviation in the age of the players recruited. A large standard deviation was seen in many of the parameters reported, this was due to variations in the magnitude of many of the parameters between the participants, however the direction of the changes seen were common among the participants which accounts for the significant differences seen, and supports the conclusion that a change in strategy occurs due to fatigue. In addition, no direct measures of the amount of pronation or pronation velocity were taken. Furthermore, greater fatigue has been previously reported as a competition progresses, however this current study did not report how many matches were played at the time of assessment, although the match duration was similar to that reported by Abián-Vicén, Castanedo, Abián, & Sampedro (2013).

Conclusion

In conclusion, this study found that players have different strategies when moving to the dominant and non-dominant sides during lunge to the net tasks. Under a fatigue state the plantar pressure shifts to the medial aspect of the midfoot in the trail limb indicating a reduction in control of the midfoot and collapse of the arch. This could account for the higher injury risk in the non-dominant trail limb which has been previously reported in badminton players, therefore further work should consider both the lead and trail foot. These results provide new insights into the changes in foot function in a fatigued state, which could possibly be managed using foot orthoses.

Disclosure statement

There is no conflict of interest reported by authors.

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Supporting information

S1 Fig. Non-dominant and dominant lunge to the net movement

S2 Fig. Net and shuttlecock position during test

S3 Fig. Pressure zone distribution and sensor configuration

S1 Table. Peak pressure in kilopascals (Kpa) for lead foot

S2 Table. 2 Mean pressure in kilopascals (Kpa) for lead foot

S3 Table. Peak pressure in kilopascals (Kpa) for trail foot

S4 Table. Mean pressure in kilopascals (Kpa) for foot trail foot

Table 1 Peak pressure in kilopascals (Kpa) for lead foot

Parameter	**LD task Mean (Kpa) ± SD**		**LND task Mean (Kpa) ± SD**		***p*-value Interaction**	***p*-value Pre - Post**	**η_p^2**	***p*-value Lunge Dom**	**η_p^2**
	Pre	**Post**	**Pre**	**Post**					
Hallux	2450.9±901.6	2520.6±1127.4	2702.4±570.4	2315.6±1117.1	0.170	0.460	0.05	0.913	0.00
2nd 3rd Phal	2503.1±818.5	2257.9±1328.3	2584.6±793.7	2269.5±1150.3	0.731	0.284	0.10	0.716	0.01
4th 5th Phal *	1698.5±1190.7	851.6± 1022.5	1548.3±993.5	1206.±1132.4	0.268	**0.035**	**0.32**	0.457	0.05
1st Met	1887.9±911.9	1966.7±1006.0	2209.0±829.7	2135.30±841.1	0.475	0.991	0.000	0.058	0.27
2nd 3rd Mets ‡	1616.1±779.3	1858.1±919.5	1981.0±922.8	1435,6±742.2	**0.011**	0.595	0.02	0.799	0.01
4th 5th Mets	1053.7± 1076.9	1198.1±1283.7	1261.9±1028.6	1212.74±1215.7	0.301	0.857	0.00	0.317	0.08
Med-midfoot	1190.5±1034.4	1318.5± 1170.2	1058.8±852.4	1386.3±944.6	0.569	0.393	0.06	0.796	0.01
Lat-midfoot	1548.9±1034.9	1423.0±1159.5	1290.0±843.5	1660.2±1295.1	0.146	0.618	0.02	0.893	0.00
Calcaneus	1960.4±931.5	1770.9±916.8	2043.9±797.5	1827.2±968.6	0.893	0.306	0.09	0.309	0.09

* significant difference between Pre and Post † significant difference between Lunge Dominance

‡ significant interaction between Pre and post and Lunge Dominance

Table 2 Mean pressure in kilopascals (Kpa) for lead foot

Parameter	LD task Mean (Kpa) ± SD		LND task Mean (Kpa) ± SD		*p*-value Interaction	*p*-value Pre - Post	η_p^2	*p*-value Lunge Dom	η_p^2
	Pre	Post	Pre	Post					
Hallux	867.8± 507.2	790.8± 490.5	783.9± 297.1	719.6± 517.1	0.920	0.432	0.05	0.303	0.09
2nd 3rd Phal	636.1± 518.1	541.19± 397.2	615.0± 391.25	532.5± 374.6	0.883	0.380	0.07	0.736	0.01
4th 5th Phal *	966.4± 767.5	475.49± 613.9	956.9± 706.13	643.0± 609.1	0.496	**0.031**	**0.33**	0.394	0.06
1st Met	670.8± 350.2	612.53± 355.6	750.2± 381.58	621.3± 310.8	0.354	0.331	0.08	0.374	0.07
2nd 3rd Mets	397.2± 206.4	361.56± 193.8	405.5± 159.04	305.8± 168.1	0.220	0.176	0.15	0.459	0.05
4th 5th Mets	227.8± 193.1	182.28± 168.7	256.5± 193.29	193.4± 185.3	0.667	0.225	0.12	0.419	0.06
Med-midfoot	298.1± 245.9	317.93± 281.9	258.9± 161.69	320.3± 198.3	0.645	0.479	0.04	0.516	0.04
Lat-midfoot	267.8± 180.2	233.94± 195.3	254.7± 185.42	266.6± 202.5	0.249	0.797	0.01	0.638	0.02
Calcaneus †	635.2± 389.9	538.08± 276.8	661.6± 386.04	596.2± 319.4	0.532	0.327	0.08	**0.032**	**0.33**

* significant difference between Pre and Post † significant difference between Lunge Dominance

‡ significant interaction between Pre and post and Lunge Dominance

Table 3 Peak pressure in kilopascals (Kpa) for trail foot

Parameter	LD task Mean (Kpa) ± SD		LND task Mean (Kpa) ± SD		*p*-value Interaction	*p*-value Pre - Post	η_p^2	*p*-value Lunge Dom	η_p^2
	Pre	**Post**	**Pre**	**Post**					
Hallux1 †	2347.9±806.9	1984.4±1161.8	2116.3±840.5	1619.1±1052.7	0.671	0.083	0.23	**0.008**	**0.45**
2nd 3rd Phal ‡	1749.7±965.0	1347.5±837.0	1250.5±837.0	1535.8±1051.3	**0.017**	0.460	0.05	0.615	0.02
4th 5th Phal †	1040.5±851.5	764.2± 745.7	673.2± 723.9	492.6± 588.0	0.463	0.198	0.13	**0.026**	**0.35**
1st Met *	2382.0±915.2	1948.0±1036.1	2211.8±1070.1	1870.6±874.2	0.757	**0.048**	**0.29**	0.473	0.04
2nd 3rd Mets	1365.3±993.5	1123.2±653.8	1413.7±1034.5	1203.5±755.8	0.863	0.204	0.13	0.542	0.03
4th 5th Mets	1627.2±1038.0	1265.5±1082.4	1336.8±1179.0	1102.1±986.1	0.575	0.084	0.23	0.106	0.20
Med-midfoot *	576.3± 371.3	967.2± 608.7	595.6± 558.2	998.0± 726.4	0.966	**0.022**	**0.37**	0.837	0.00
Lat-midfoot	910.6± 916.8	875.0± 855.3	1146.9±1220.1	735.1± 692.4	0.191	0.288	0.09	0.702	0.01
Calcaneus	638.4± 415.3	456.1± 279.2	583.5± 332.7	563.4± 376.0	0.095	0.167	0.15	0.659	0.02

* significant difference between Pre and Post † significant difference between Lunge Dominance

‡ significant interaction between Pre and post and Lunge Dominance

Table 4 Mean pressure in kilopascals (Kpa) for foot trail foot

Parameter	LD task Mean (Kpa) ± SD		LND task Mean (Kpa) ± SD		*p*-value Interaction	*p*-value Pre - Post	η_p^2	*p*-value Lunge Dom	η_p^2
	Pre	Post	Pre	Post					
Hallux * †	649.8± 318.4	488.5± 302.2	560.85± 245.9	425.06± 329.0	0.811	**0.020**	**0.38**	**0.038**	**0.31**
2nd 3rd Phal	336.8± 219.9	221.7± 159.3	291.76± 239.0	254.67± 190.2	0.101	0.067	0.25	0.806	0.01
4th 5th Phal †	564.6± 453.3	408.7± 383.6	376.04± 395.08	280.43± 312.5	0.349	0.175	0.15	**0.017**	**0.39**
1st Meta *	804.1± 439.2	645.1± 501.3	721.71± 353.45	576.00± 286.0	0.869	**0.046**	**0.29**	0.312	0.09
2nd 3rd Meta	354.8± 233.7	284.2± 161.2	406.64± 240.6	323.44± 172.7	0.711	0.113	0.20	0.120	0.19
4th 5th Meta	300.9± 192.7	271.3± 264.2	246.46± 163.32	223.26± 198.4	0.791	0.449	0.05	0.130	0.18
Med-midfoot *	155.3± 79.8	225.7± 122.5	138.82± 103.71	216.72± 147.7	0.889	**0.046**	**0.29**	0.623	0.02
Lat-midfoot	174.5± 135.5	162.9± 146.5	195.1± 170.17	128.49± 114.1	0.138	0.177	0.15	0.619	0.02
Calcaneus	229.0± 139.1	208.0± 154.1	236.27± 150.6	237.8± 182.8	0.378	0.813	0.01	0.372	0.07

* significant difference between Pre and Post † significant difference between Lunge Dominance

‡ Significant interaction between Pre and post and Lunge Dominance

Figure 1. Non-dominant and dominant lunge to the net movement

Figure 2. Net and shuttlecock position during test

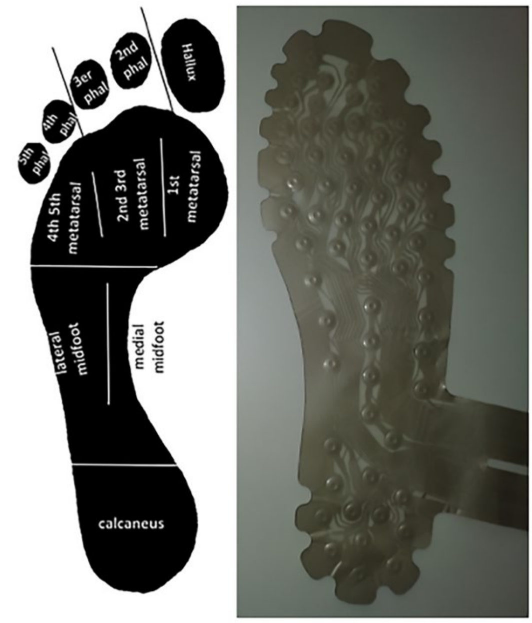

Figure 3. Pressure zone distribution and sensor configuration