METHODS AND THEORETICAL PERSPECTIVES

Basketball layup – Foot loading characteristics and the number of trials necessary to obtain stable plantar pressure variables

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Abstract

This study aimed (1) to profile the plantar loading characteristics when performing the basketball layup in a realistic setting, and (2) to determine the number of trials necessary to establish a stable mean for plantar loading variables during the layup. Thirteen university male basketball players [age: 23.0 (1.4) years, height: 1.75 (0.05) m, mass: 68.4 (8.6) kg] performed ten successful basketball layups from a stationary position. Plantar loading variables were recorded using the Novel Pedar-X in-shoe system. Loading variables including peak force, peak pressure, and pressure time integral were extracted from eight foot regions. Performance stability of plantar loading variables during the takeoff and landing steps were assessed using the sequential averaging technique and intra-class correlation coefficient (ICC). High plantar loadings were experienced at the heel during the takeoff steps, and both the heel and forefoot regions upon landing. The sequential estimation technique revealed a five to eight trial range to achieve a stable mean across all plantar loading variables whereas ICC analysis was insensitive to inter-trial differences of repeated layup performances. Future studies and performance evaluation protocols on plantar loading during basketball layups should include at least eight trials to ensure that the measurements obtained are sufficiently stable.

Keywords: *Performance stability, sequential estimation, force, peak pressure, pressure time integral*

Word Count (abstract): 199

Introduction

During basketball games, the layup is the most commonly employed method of scoring (Wang, Liu, & Moffit, 2009). The layup consists of the approach, takeoff, and landing phases. In the evaluation of basketball footwear, the layup has been recommended over traditional drop-landing tasks when comparing biomechanical and subjective variables between shoes (Lam, Sterzing, & Cheung, 2011; Nin, Lam, & Kong, 2016).

A few studies have examined the foot loading characteristics during the layup (Guettler et al., 2006; Pau & Ciuti, 2012; Queen, Mall, Nunley, & Chuckpaiwong, 2009; Yu et al., 2007). Guettler and colleagues (2006) and Yu and co-workers (2007) reported conflicting results on plantar forces or pressures with and without the use of orthoses during simulated layups. Both studies only reported data specific to the fifth metatarsal area. Pau and Ciuti (2012) profiled the plantar pressure of the forefoot, midfoot and rearfoot during the layup in female basketball players. The layup tasks, however, were performed barefooted which may not reflect foot loading while wearing shoes. Queen and colleagues (2009) investigated the plantar loading between flat and normal feet during simulated layups. While comprehensive data in eight foot regions were presented, the results may be influenced by different footwear since participants wore their personal shoes. It should also be noted that most previous studies examined simulated basketball layups in laboratory environment in which participants may not perform the task naturally (Guettler et al., 2006; Pau & Ciuti, 2012; Queen et al., 2009; Yu et al., 2007). To better understand foot loading characteristics during the layup, it will be beneficial to profile plantar pressure distribution using standardised footwear in a realistic basketball court setting.

Given the large volume of data associated with plantar loading measurements, it is critical to select an appropriate number of trials in the test protocol (James, Herman, Dufek, & Bates, 2007). As variability exists in all human movement, using too few trials may not represent an individual's long-term performance (Bates, Osternig, Sawhill, & James, 1983). On the other hand, collecting too many trials may impose unnecessary burden and fatigue on the participants (Amiri-Khorasani, Osman, & Yusof, 2010), as well as prolonging data processing time. To date, there is no guideline on the number of trials required to achieve performance stability in the basketball layup. Here, stability of a performance refers to the repeatability of a variable across repeated trials over time (James, Herman, Dufek, & Bates, 2007). Earlier studies on plantar loading during basketball tasks either did not specify how many trials were used (Guettler et al., 2006), or averaged from three (Pau & Ciuti, 2013; Yu et al., 2007) to five (Queen et al., 2009) trials arbitrarily. It remains uncertain whether the data obtained were sufficient to represent typical loading behaviours. Other biomechanical studies examining athletic tasks involving high impact activities have established a range of four to twelve trials to achieve performance stability for kinetic and kinematic variables (Bates et al., 1983; James et al., 2007; Racic, Pavic, & Brownjohn, 2009; Rodano & Squadrone, 2002). To our best knowledge, there have been no studies investigating the influence of trial number on the stability of plantar loading parameters of any movements.

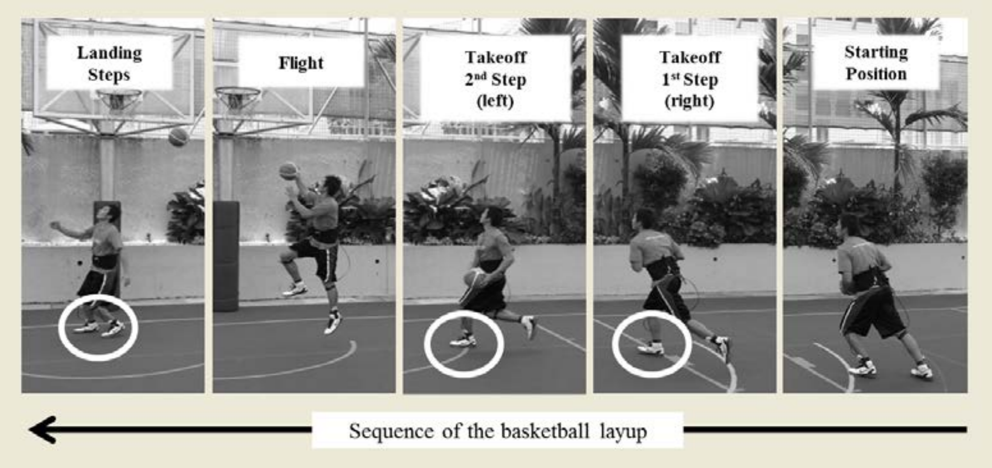
Therefore, the purposes of this study were (1) to profile the plantar loading characteristics when performing the layup in a basketball court using standardised footwear, and (2) to determine the number of trials necessary to obtain stable plantar loading measurements during the layup. It was hypothesised that (1) the loading patterns would vary across the different layup steps with higher loads at the heel and forefoot regions (Pau & Ciuti, 2 013), and (2) stability of the data would improve with the number of trials used to calculate the mean, until a point beyond which further increasing the number of trials would not influence the mean value substantially.

Methods

Thirteen healthy male university basketball players [age: 23.0 (1.4) years, height: 1.75 (0.05) m, mass: 68.4 (8.6) kg, foot size: either US 9.0 or 11.0] who participated in the Institute Inter-hall Basketball Games 2014 were recruited for the study. All participants had more than five years of recreational basketball experience and were free from any lower-extremity injuries for six months prior to the time of study. All except one participant were right-handed. The procedures were approved by the Nanyang Technological University Institutional Review Board. The experiment took place in an indoor wooden basketball court. Two pairs (US 9.0 or 11.0) of standardised basketball shoes (Nike Black Mumba 24, Portland, USA) were used across all participants.

Each participant performed ten successful right-handed basketball layups approaching from the right side of the rim (Figure 1). Participants started off from a stationary position which was determined by self-preference and was fixed for all trials within a participant. After two contralateral takeoff steps (right, followed by left), the ball was released in mid-air before participants landed on both feet. This layup task was designed to simulate the receipt of a chest-pass and subsequent execution of a layup, with no dribbling allowed throughout the movement (Nin et al., 2016). An attempt was considered successful if the ball passed through the basket, or had contact with both the backboard and the rim.

Figure 1: The sequence of basketball layup approaching from the right side of the rim.



Plantar loading variables were recorded at 100 Hz using the Novel Pedar-X in-shoe system (Novel GmbH, Munich, Germany). This system has been demonstrated to be valid and reliable in the assessment of in-shoe plantar loading distribution (Boyd, Bontrager, Mulroy, & Perry, 1997; Putti, Arnold, Cochrane, & Abboud, 2007). Before the actual trial, participants were given sufficient time to warm up and be familiarised with the provided footwear and the in-shoe system. Loading variables including peak force (PF), peak pressure (PP), and pressure time integral (PTI) were extracted from eight regions (hallux, lesser toes, medial, central and lateral forefoot, medial and lateral arch, and heel) as well as the whole foot. The PF indicates the maximal force (in N) while PP represents the maximal pressure (in kPa) in one foot region during one step. The PTI describes the cumulative effect of pressure over time (in kPa·s) in a certain region of the foot to demonstrate the total pressure exposure during one step. These variables are commonly used in understanding the loading at various regions of the foot during athletic tasks (Cheng, Mao, Fong, & Hong, 2005; Guettler et al., 2006; Queen et al., 2009). To address our first aim, the ten-trial mean of each variable was used to represent the plantar loading characteristics during the takeoff and landing steps of the layup. This descriptive approach has been adopted in previous studies profiling ground reaction forces and kinematics during layup takeoff and landing in professional basketball players (McClay et al., 1994a; McClay et al., 1994b). For the second aim, two methods were carried out to assess performance stability of plantar loading variables:

(1) Sequential averaging technique (Bates et al., 1983) – For each participant's set of ten trials, a value was generated for the cumulative mean by adding one trial at a time. Stability of a plantar loading variable was achieved as soon as a pre-defined criterion was observed. Here, the criterion to obtain a stable mean for each plantar loading variable was met when the cumulative mean fell within ± 0.25 standard deviation of the ten-trial mean, and stayed there for the remaining trials. Details of this method were described elsewhere in the literature (Bates et al., 1983; James et al., 2007; Rodano & Squadrone, 2002). Using this technique, the number of trials

necessary to reach a stable mean for each participant and variable was calculated.

(2) Intra-class Correlation Coefficient (ICC) – To assess the reliability of data with an increasing number of trials, the ICC for single measures (one-way random) was applied repeatedly in increments of one trial (1-2, 1-3, … 1-10 trials). Interpretation of ICC was stratified according to guidelines adopted by Montero-Odasso et al. (2009): < 0.4 (poor), $0.40 \leq$ ICC ≤ 0.59 (fair), $0.60 \leq$ ICC ≤ 0.74 (good) and $0.75 \leq$ ICC ≤ 1.00 (excellent).

Results

Table 1 presents the ten-trial mean (standard deviation) of the plantar loading variables in each of the eight foot regions obtained across the different steps in the basketball layup. For the two takeoff steps, higher PF and PP were generally observed at the heel compared with other foot regions. During the double-leg landing, the right foot experienced higher loading than the left foot overall with relatively higher PF and PP at the heel and forefoot regions. Among all four steps in the layup, the highest loading was seen at the second (left) takeoff step [PF (694.1 N) and PP (410.3 kPa)].

*** Table 1 about here ***

For the sequential averaging technique that used ten reference trials and a 0.25 standard deviation criterion value, participants took five to eight trials to achieve stability across all plantar loading variables (Table 2). Generally, ICC results remained relatively consistent regardless of the number of trials used (Table 3). Higher reliability was observed in the takeoff compared with the landing steps, with most ICC > 0.75 across all foot regions during the first and second takeoff steps (Table 4). Overall, ICC results indicated fair to excellent reliability for PF and PP variables, with slightly lower values for PTI (Table 4).

*** Tables 2 to 4 about here ***

Discussion and implications

The first purpose of this study was to provide a descriptive profile of the plantar loading distribution during the basketball layup using standardised footwear in a realistic playing environment. The results supported our first hypothesis that the plantar loading distribution varied among the different footsteps in a layup. Our observations of higher PF and PP at the heel region during the takeoff steps were in agreement with the study by Pau and Ciuti (2013), which similarly demonstrated greater peak forces at the heel during the initial phases of the layup measured under a barefoot condition. The highest PF (694.1 N) and PP (410.3 kPa) were noted during the second takeoff (left) step of the layup in our study. Since this step contributes towards propulsion into the flight phase, it is not surprising as higher forces are needed to achieve reasonable jump heights.

During landing, the forefoot and heel areas experienced higher loading than other foot regions. This is in agreement with a previous study on simulated layup landings (Valiant & Cavanagh, cited in McClay et al., 1994b) in which peak ground reaction forces (GRF) were observed in the forefoot and heel regions based on centre of pressure (COP) patterns. When landing from a jump, freestyle figures skaters demonstrated a smaller range of COP in the anteroposterior direction in comparison with non-skaters (Saunders, Hanson, Koutakis, Chaudhari, & Devor, 2014). The skater's COP lay in the mid to forefoot region during landing, which may be related to their training background. In our study, our participants may have shifted their COP anteriorly, resulting in high loading at the forefoot region. We speculated that the higher forefoot loading might reflect participants' preparation to propel forward for the next move due to the continuous nature of the sport which requires players to immediately get back into position after scoring. In addition, we observed relatively high loading at the heel regions. In line with our findings, Queen and co-workers (2009) also reported the greatest forces at the rearfoot during a landing task. Nin and colleagues (2016) measured the landing forces from a layup using a woodentop force platform to simulate basketball playing surface. They found that the peak GRF, which occurred during the later stage of layup landing, was associated with rearfoot contact. This supports our finding of higher loading at the heel region. In summary, this study has shown that the plantar loading distribution varied across the different steps of the basketball layup, with high PF and PP generally occurring at the forefoot and/or heel regions. Future studies can further examine how the use of footwear and orthoses may contribute to reducing the risk of injuries through providing cushioning to specific regions of the foot.

The second aim of this study was to determine the minimum number of trials required to obtain stable plantar loading data when performing the basketball layup. A stable set of data is necessary for both the reliability and validity of the outcome of a measured variable (James et al., 2007). It is therefore an important methodological consideration to determine the number of trials to be collected in the evaluation of sports movements. Results obtained using the sequential averaging technique support our second hypothesis that stability of the plantar loading data would improve with the number of trials used to calculate the mean, until a point beyond which further increasing the number of trials would not influence the mean value substantially. The ICC analysis, however, did not demonstrate a trend of improving reliability despite increasing the number of trials used.

Using the sequential averaging technique, the number of trials required for stable measurement varied from five to eight across the different layup steps, variables of interest, and regions of the foot (Table 2). The current results are comparable to the previously reported four to nine trial range necessary to establish stable GRF variables during running, jumping and landing (Bates et al., 1983; James et al., 2007; Racic et al., 2009). In our study, plantar loading variables during the takeoff steps are more stable than the landing steps. In addition, loading at the toes and forefoot regions appear more stable than at the midfoot and heel regions. For all plantar loading variables analysed, the medial arch region during the left foot landing of a layup required the highest number of trials to reach stable performance. Based on these data, it would appear that a minimum of eight trials were necessary in order to obtain stable plantar loading variables across all foot regions when performing a basketball layup.

Our choice of the 0.25 standard deviation as a criterion for the stability of data in the sequential averaging technique may be of concern. This criterion represented a conservative cut-off and was arbitrarily chosen as a compromise between the need to obtain rather stable results and the attempt to keep the mean total number of trials as low as possible (Rodano & Squadrone, 2002). Using smaller criterion values (e.g. 0.15, 0.20) would provide more conservative estimates of stability (James et al., 2007), resulting in higher number of trials to achieve stability. Conversely, greater criterion values (e.g. 0.30, 0.35) might underestimate the number of trials, given the cumulative mean might repeatedly fall within the criterion value bandwidth (Rodano & Squadrone, 2002). Nonetheless, the criterion value of 0.25 standard deviation was commonly adopted in many studies investigating human movement tasks (Bates et al., 1983; James et al., 2007). Therefore, it is believed that this criterion value was appropriate for the basketball layup technique examined in this study.

The ICC analysis did not demonstrate a trend of improving reliability despite increasing the number of trials used (Table 3). This suggests that the ICC analysis is insensitive to inter-trial differences of repeated layup performances and therefore unable to specify a trial whereby stable performance was achieved for this movement task. During the takeoff steps of the basketball layup, good to excellent reliability were achieved for most variables (ICC > 0.60) across all foot regions (Table 4). Contrary to our findings, previous studies have shown that the ICC analysis method was able to detect the number of trials required for stable GRFs during continuous jumping (Racic et al., 2009) and landing (James et al., 2007). Our study investigated a commonly performed task (layup) in a regular basketball court, with sufficient practice time provided for our participants before data collection. It is possible that the nature of plantar loading variables during basketball layups is more consistent than that of GRFs during other unaccustomed jumping and landing tasks in laboratory settings (James et al., 2007; Racic et al., 2009). Thus, the ICC analysis method might not be sufficiently sensitive to determine the exact number of trials whereby plantar loading variables for the basketball layup became stabilised.

Establishing a minimum number of trials for stable performance in this study might contribute towards enhancing research and performance evaluation protocols in basketball. When conducting experiments on human participants, it is beneficial to limit the number of trials to the minimum and yet obtaining representative data. The present study established a minimum of eight trials for obtaining stable plantar loading measurements across all foot regions. This finding eliminates the use of arbitrary selected trials as in previous studies (Pau & Ciuti, 2013; Queen et al., 2009; Yu et al., 2007) and allows for ease of implementation. This approach can benefit researchers, coaches and athletes by minimising the burden imposed on participants, reducing the influence of fatigue on movements (Amiri-Khorasani et al., 2010), and avoiding unnecessary data processing time. From a clinical perspective, it is also important to assure that plantar loading characteristics are measured using a sound test protocol to better understand possible risks of foot injuries (Guettler et al., 2006; Yu et al., 2007). Although many studies have used plantar loading variables to assess loading during sports movements (e.g. Cheng et al., 2005; Pau & Ciuti, 2013; Queen et al., 2009; Yu et al., 2007), little is known regarding the performance stability of plantar loading data. This study examined the basketball layup task to provide insight on plantar loading during running jumps and landings on hard surfaces. Future studies can further explore the performance stability of plantar loading variables in other movements such as sprinting and cutting.

There are a few limitations in our study. First, only layups starting from a stationary position were examined and therefore the results cannot be generalised to layups performed while a player is running (e.g. layup executed during a fast break). We acknowledged that this is a limitation from the perspective of ecological validity since running layups are often performed in a basketball game situation. It is possible that running layups in a dynamic environment are inherently more variable; hence our results may have underestimated the number of trials required for stable performances. On the other hand, our protocol of simulating a layup upon the receipt of a chest-pass is highly relevant to footwear research and testing protocols whereby standardising the initial speed across conditions and trials are essential (Nin et al., 2016). The second limitation was that foot morphology of the participants was not considered in this study. We recognise that foot types (e.g. low and high arches) may play a role in influencing the resulting plantar loading characteristics (Guettler et al., 2006; Queen et al., 2009) and subsequently the number of trials needed to achieve performance stability. We also did not take into account the participants' playing positions (e.g. guard, forward, or centre) which may have contributed to different layup loading mechanics. Finally, our participants were recreational basketball players competing at the university level and therefore the results may not be applicable to players of other abilities (e.g. professional) due to differences in skill competencies (Nin et al., 2016). Despite the limitations, it is believed that the results of this study would be applicable to a general population of recreational basketball players. Future studies can further investigate how the plantar loading profiles and the number of trials required to achieve stable performance will be influenced by starting approach (i.e. stationary versus running), foot types, playing positions, and skill levels.

Conclusion

This study provided information on the foot loading characteristics experienced by recreational basketball players during the layup task. High plantar loadings were experienced at the heel during the takeoff steps, and both the heel and forefoot regions upon landing. Additionally, the present study recommended a minimum of eight trials for obtaining stable plantar loading measurements across all foot regions when performing a basketball layup. Establishing an appropriate number of trials may benefit researchers, coaches and athletes by minimising the burden imposed on participants, reducing the influence of fatigue on movements, and avoiding unnecessary data processing time. While the ICC analysis was relatively insensitive to inter-trial differences of repeated layup tasks, the sequential estimation technique appeared as a useful tool for determining the number of trials required to reach performance stability.

Word count (main text) = 3,365

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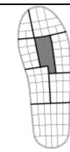
Table 1. Ten-trial mean (standard deviation) of peak force (N), peak pressure (kPa) and pressure time integral (kPa·s) obtained during the basketball layup.

Illustration	**Step**	**Variable**	 **Hallux**	 **Lesser Toes**	 **Medial Forefoot**	 **Central Forefoot**	 **Lateral Forefoot**	 **Medial Arch**	 **Lateral Arch**	 **Heel**
	Takeoff (right)	PF	82.6 (42.3)	187.0 (58.4)	179.2 (71.0)	290.4 (53.4)	121.9 (50.9)	67.0 (45.0)	104.0 (41.7)	323.2 (139.6)
		PP	241.7 (96.3)	268.9 (85.1)	331.2 (89.5)	303.2 (71.5)	134.4 (47.2)	75.9 (35.8)	91.3 (31.2)	196.8 (79.0)
		PTI	34.2 (14.0)	39.3 (12.4)	53.2 (14.4)	48.4 (11.6)	21.7 (8.3)	12.1 (12.8)	16.4 (11.1)	21.2 (11.3)
	Takeoff (left)	PF	96.1 (53.7)	293.9 (83.9)	157.2 (42.0)	347.6 (52.2)	284.8 (79.0)	90.9 (37.5)	216.8 (51.1)	694.1 (162.1)
		PP	296.5 (117.3)	338.5 (70.3)	246.2 (80.5)	271.0 (65.6)	235.8 (52.9)	115.4 (29.3)	182.0 (35.9)	410.3 (67.2)
		PTI	36.1 (16.6)	46.3 (9.6)	32.7 (11.8)	37.4 (9.3)	38.6 (9.2)	13.3 (5.1)	26.8 (7.2)	35.8 (8.4)
	Landing (right)	PF	70.6 (32.4)	199.0 (49.7)	146.4 (48.9)	278.0 (72.5)	188.6 (64.9)	142.0 (85.4)	203.7 (84.4)	424.7 (219.1)
		PP	210.4 (86.9)	272.9 (97.4)	291.9 (94.5)	283.0 (92.8)	194.6 (38.6)	160.4 (60.1)	185.2 (55.6)	258.4 (128.5)
		PTI	62.1 (34.4)	82.1 (36.6)	79.1 (44.5)	86.9 (46.8)	58.3 (27.5)	21.5 (18.6)	27.2 (17.9)	30.9 (23.0)
	Landing (left)	PF	101.2 (39.4)	162.3 (60.1)	181.6 (53.0)	258.3 (40.8)	163.6 (53.8)	98.8 (78.6)	144.5 (75.0)	197.8 (166.8)
		PP	264.0 (86.4)	221.8 (74.3)	261.4 (70.8)	234.0 (38.2)	193.9 (69.1)	101.7 (65.0)	140.2 (60.4)	124.9 (84.1)
		PTI	38.6 (18.9)	33.8 (19.6)	36.0 (17.3)	30.4 (13.1)	20.5 (11.6)	5.8 (6.1)	9.0 (7.3)	8.35 (9.7)

PF = peak force (N), PP = peak pressure (kPa), PTI = pressure time integral (kPa·s).

Table 2. Mean (standard deviation) number of trials required for stable plantar loading variables using the sequential averaging technique.

Illustration	Step	Variable	 Hallux	 Lesser Toes	 Medial Forefoot	 Central Forefoot	 Lateral Forefoot	 Medial Arch	 Lateral Arch	 Heel	 Whole Foot
	Takeoff (right)	PF	7 (2)	6 (3)	7 (2)	7 (2)	6 (2)	6 (2)	8 (1)	7 (3)	7 (2)
		PP	7 (2)	6 (2)	7 (2)	7 (2)	7 (2)	7 (2)	6 (2)	6 (3)	7 (1)
		PTI	7 (2)	6 (2)	7 (2)	6 (2)	6 (2)	7 (2)	7 (1)	6 (3)	7 (2)
	Takeoff (left)	PF	7 (2)	7 (2)	7 (2)	7 (2)	7 (1)	7 (2)	6 (3)	6 (2)	6 (2)
		PP	7 (3)	7 (2)	7 (2)	6 (2)	6 (2)	7 (2)	6 (2)	7 (2)	7 (2)
		PTI	7 (2)	7 (2)	7 (2)	7 (2)	6 (1)	7 (2)	6 (2)	6 (2)	6 (2)
	Landing (right)	PF	7 (2)	7 (1)	6 (2)	7 (2)	7 (2)	6 (2)	6 (2)	6 (2)	6 (2)
		PP	6 (2)	7 (2)	5 (2)	6 (2)	6 (2)	6 (2)	5 (2)	6 (2)	6 (1)
		PTI	6 (1)	6 (2)	6 (2)	6 (2)	6 (2)	7 (2)	7 (2)	7 (1)	6 (2)
	Landing (left)	PF	6 (2)	6 (2)	7 (2)	6 (3)	6 (2)	8 (1)	7 (2)	8 (2)	8 (1)
		PP	6 (2)	7 (3)	7 (2)	6 (2)	6 (2)	8 (1)	7 (2)	8 (2)	5 (2)
		PTI	6 (2)	6 (2)	7 (2)	7 (2)	7 (2)	8 (2)	7 (2)	7 (2)	6 (2)

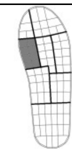
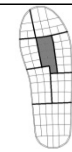
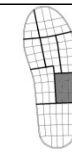
PF = peak force, PP = peak pressure, PTI = pressure time integral.

Table 3. Intra-class Correlation Coefficient for plantar loading variables of the whole foot.

Illustration	Step	Variable	Number of trials used 1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
	Takeoff (right)	PF	0.97	0.97	0.94	0.95	0.91	0.92	0.93	0.93	0.94
		PP	0.70	0.62	0.57	0.55	0.60	0.63	0.60	0.63	0.65
		PTI	0.60	0.69	0.58	0.52	0.52	0.53	0.52	0.53	0.51
	Takeoff (left)	PF	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98
		PP	0.47	0.52	0.23	0.39	0.43	0.46	0.37	0.36	0.37
		PTI	0.29	0.48	0.57	0.63	0.66	0.65	0.67	0.68	0.67
	Landing (right)	PF	0.84	0.76	0.78	0.79	0.81	0.82	0.83	0.83	0.83
		PP	0.86	0.62	0.62	0.57	0.59	0.63	0.66	0.68	0.67
		PTI	0.32	0.44	0.54	0.61	0.61	0.64	0.66	0.67	0.68
	Landing (left)	PF	0.77	0.66	0.72	0.62	0.64	0.64	0.64	0.62	0.63
		PP	0.63	0.77	0.75	0.70	0.69	0.68	0.67	0.68	0.63
		PTI	0.80	0.56	0.67	0.69	0.43	0.48	0.48	0.52	0.40

PF = peak force, PP = peak pressure, PTI = pressure time integral.

Table 4. Range of Intra-class Correlation Coefficients obtained across all trial increment levels (1-2, 1-3, … 1-10 trials).

Illustration	**Step**	**Variable**	 **Hallux**	 **Lesser Toes**	 **Medial Forefoot**	 **Central Forefoot**	 **Lateral Forefoot**	 **Medial Arch**	 **Lateral Arch**	 **Heel**	 **Whole Foot**
	Takeoff (right)	PF	0.96 – 0.97	0.84 – 0.90	0.91 – 0.96	0.80 – 0.87	0.80 – 0.88	0.86 – 0.90	0.86 – 0.95	0.68 – 0.86	0.91 – 0.97
		PP	0.93 – 0.96	0.86 – 0.90	0.78 – 0.83	0.84 – 0.92	0.75 – 0.85	0.86 – 0.90	0.82 – 0.86	0.71 – 0.86	0.55 – 0.70
		PTI	0.87 – 0.94	0.73 – 0.81	0.57 – 0.73	0.44 – 0.74	0.60 – 0.79	0.81 – 0.96	0.37 – 0.46	0.83 – 0.88	0.51 – 0.69
	Takeoff (left)	PF	0.94 – 0.96	0.95 – 0.97	0.71 – 0.83	0.93 – 0.97	0.93 – 0.95	0.93 – 0.95	0.83 – 0.91	0.87 – 0.89	0.96 – 0.98
		PP	0.87 – 0.92	0.80 – 0.84	0.84 – 0.91	0.93 – 0.96	0.82 – 0.89	0.83 – 0.88	0.66 – 0.78	0.53 – 0.76	0.23 – 0.52
		PTI	0.85 – 0.89	0.77 – 0.83	0.84 – 0.89	0.88 – 0.94	0.87 – 0.92	0.92 – 0.95	0.81 – 0.90	0.71 – 0.84	0.29 – 0.68
	Landing (right)	PF	0.85 – 0.97	0.76 – 0.87	0.70 – 0.90	0.79 – 0.86	0.81 – 0.90	0.74 – 0.81	0.69 – 0.83	0.51 – 0.67	0.76 – 0.84
		PP	0.81 – 0.96	0.83 – 0.89	0.67 – 0.90	0.75 – 0.94	0.63 – 0.72	0.57 – 0.67	0.50 – 0.63	0.54 – 0.71	0.57 – 0.86
		PTI	0.31 – 0.64	0.23 – 0.60	0.37 – 0.67	0.34 – 0.70	0.28 – 0.52	0.62 – 0.72	0.55 – 0.68	0.38 – 0.89	0.32 – 0.68
	Landing (left)	PF	0.84 – 0.90	0.88 – 0.93	0.73 – 0.81	0.49 – 0.66	0.74 – 0.79	0.74 – 0.86	0.39 – 0.62	0.55 – 0.74	0.62 – 0.77
		PP	0.77 – 0.86	0.84 – 0.86	0.17 – 0.83	0.52 – 0.74	0.70 – 0.81	0.74 – 0.92	0.24 – 0.61	0.53 – 0.66	0.63 – 0.77
		PTI	0.56 – 0.91	0.62 – 0.89	0.38 – 0.84	0.40 – 0.91	0.48 – 0.70	0.32 – 0.87	0.36 – 0.72	0.37 – 0.71	0.40 – 0.80

PF = peak force, PP = peak pressure, PTI = pressure time integral.