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Ground Reaction Forces attenuation in supinated and pronated foot during single leg drop-landing

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ABSTRACT

The aim of this study was to compare the peak Vertical Ground Reaction Forces (VGRF) and Rate of Loading (ROL) between supinated, pronated, and normal feet during single leg drop-landing. Thirty healthy male students from physical education & sport sciences department participated in this study and assigned to one of three groups by navicular drop test (10 per groups) [pronated (≥10mm), neutral (5-9mm), or supinated (≤4mm)]. Participants performed single leg drop-landing on the force plate from the box with height of 0.30 m. Peak VGRF and ROL were calculated using GRF data. There were significant differences in ROL between three groups ($F_{2, 22}$=15.553, Wilks' Lambda = 0.370, P≤0.05) but differences in Peak VGRF were not significant between them ($F_{2, 22}$ = 2.632, P >0.05). These results suggest that supinated foot is associated with specific lower extremity kinetics. Differences in these parameters may subsequently lead to differences in injury patterns in supinated and pronated foot in athletes.

Keywords: Pronated foot, Rate of loading, single leg drop-landing, supinated foot.

INTRODUCTION

The complex of lower leg, ankle, and foot is responsible for absorbing and distributing compressive, shear, bending, and tensile forces that act on the body during ground foot contact. Since the foot interfaces with the ground during dynamic activities such as gait, running and landing, structural changes may cause compensatory malalignment and mechanical deviations of the entire lower extremity [1]. Therefore, studies on persons with abnormal foot structure could provide better insight into abnormalities in lower extremity mechanics. Lower extremity malalignments, especially in foot segment, can result in mechanical deviations that increase risk of injuries for athletes [1]. For instance, the term "miserable malalignment syndrome" has been used to describe structural deviations including hip internal rotation, genu valgum, and foot pronation that are often seen in injured runners. Abnormal foot structure is also commonly implicated as a predisposing factor to injuries such as chondromalacia patella and shin splints [1, 2]. There are three broad classes of feet: neutrally aligned (the bisection of the posterior surface of the calcaneus is close to perpendicular to the ground and the arch is at a normal height), pronated foot or pes planus (the calcaneus is everted and the arch is low or absent) and supinated foot or pes cavus (the calcaneus is inverted and the arch is high) [3]. Subotnick (1985) reported that 60% of the population has normal arches, 20% have a cavus foot, and 20% have a planus foot. These latter 40% are most interesting in lower extremity mechanics, as it is commonly thought that their structure will lead to some degree of compensation in lower extremity mechanics [4].

Many athletes perform jump-landing during training activities and competitions. Research focusing on jumping seeks to understand how one generates and uses the energy necessary to propel oneself. Research on landing however, focuses on the biomechanical implications of impact and the resulting loads placed on the lower extremity tissues [5]. It is reported that landing from a jump can involve forces that are two to 12 times the body weight, which could be related to lower extremity injuries [2], therefore this has led to an increased focus on landing techniques [6].

The rate of impact-force application, or rate of loading (ROL), describes the rate of stress application to the lower extremity during landing. High stress application during a short period produces a high rate of loading, which may lead to poor shock attenuation [1, 7]. It is reported that Body weight, landing height, landing-surface composition, speed of movement, shoe type, and landing strategy affect the magnitude and rate of loading [8]. During weight bearing activities (such as landing from a jump), the lower extremities are largely responsible for the body's ability to absorb shock and decrease the rate of loading. Therefore, the recognition of factors that influence in body ability to dissipate impact forces during landing can help us to diagnose lower extremity injuries through corrective biomechanical functions.

It is reported that increase in rate of vertical loading subsequently can increase the tibial impact and knee pain [9, 10]. Imposed load on kinetic chain structures during athletic activities can increase biological strength of body component likes ligaments, tendons, muscles, bone and joint cartilages. However, providing increase in ROL, it is possible to see micro and macro degeneration in anatomical structures [11]. Since the repetitive application of high-impact forces can lead to injury and decreased performance, the ability to control and adequately absorb these forces during dynamic, functional activity is the key to prevention of injury [12]. High percent of all lower extremity injuries (approximately %70) that occur during jumping activities, can lead us to suppose high correlation between landing forces and lower extremity injuries [6]. Therefore, the examination of ROL may give better insight in differences injuries in athletes with high and low arches. Supposing that excessive pronation and supination can result in differences in peak VGRF and ROL imposed on lower extremities and consequently injury in the lower extremities, the aim of this study was to compare peak VGRF and ROL between supinated and pronated and normal foot during single leg drop-landing.

MATERIALS AND METHODS

Data Collection: Thirty male students from physical education & sport science department (mass 75.27 ± 4.70 kg, height 176.50 ± 5.30 cm, age 23 ± 3 years) participated in this study. Subjects were grouped (n= 10 per group) on the basis of weight bearing navicular drop (ND) (supinated, ≤ 4mm; neutral, 5-9 mm; pronated, ≥10 mm) [2, 13]. This study was approved by the university institutional review board. All participants signed an informed consent document approved by the Institution human subjects review board. Subjects positioned barefoot on a box 0.30 m above the landing surface with arms aligned along the shafts of the femur and the fibula. The force plate (MIE, 40 × 60) served as the landing surface and placed on the floor 0.15 m in front of the box [2](figure 1). Before testing, subjects identically were instructed about landing protocol. Subjects stood on the box in a comfortable, full weight-bearing, double-leg posision. They were instructed to drop off the box, not lower themselves from it, and perform a single-leg landing on the forceplate with preferred leg. Upon landing, subjects were encouraged to try to maintain their balance after contact with the forceplate. Subjects were allowed sufficient practice to become comfortable with the landing procedure and to determine the preferred landing leg. The preferred landing leg was defined as the leg the subject chose to land on most frequently during the first 3 practice trials. Subjects then performed drop jumps until 5 acceptable trials were recorded. Acceptable trials were defined by the following landing criteria: (1) contact of the forefoot first, (2) maintenance of balance, (3) ability to land without hopping, and (4) knee flexion less than 90° during the whole landing contact.

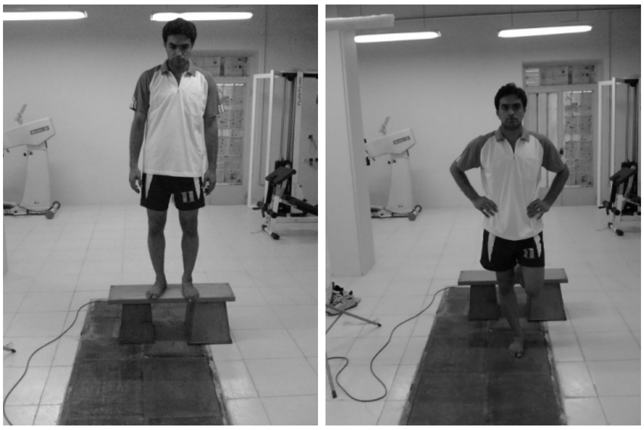

Figure 1: subject condition before and after landing

The landing data are collected on force plate at a sampling rate of 200 Hz. A fast Fourier transformation analysis indicates that the raw analog signals of a single-leg stance and the jump-landing maneuver are below 30 Hz. Therefore, a minimum sampling rate of 60 Hz would be sufficient for collecting data. The peak ground reaction forces (GRF) of the landing is a key component to calculate the ROL. A sampling rate that is too low might miss the peak force and consequently cause the ROL to be miscalculated. We selected, therefore, 200 Hz to provide a sampling rate six times greater than the raw analog-signal under study.

Subjects landing on force plate and the acquired force plate data, VGRF (z direction) and ROL were analyzed. Peak VGRF determined as the peak vertical force (N) during landing. The data were normalized with respect to body weight (N), and expressed as a multiple of body weight (×BW). Time to peak force measured as the time from initial ground contact to the peak vertical force during landing. Rate of loading was calculated as the normalized peak vertical force divided by the time to peak force.

$$ROL = \left[\frac{peakFz(N)/BW(N)}{t}\right] = \frac{BW}{ms}$$

Data Analysis: We used multivariate analysis of variance (MANOVA) at the p level of 0.05 to compare Peak VGRF and ROL between three groups.

RESULTS

The results showed significant differences in ROL between three groups of supinated, pronated, and normal foot ($F_{2,22}$=15.55, Wilks' Lambda = 0.37, P≤0.05), however differences in peak VGRF was not significant ($F_{2,22}$ = 2.63, P >0.05). It is presented the mean and standard deviation for peak VGRF and ROL and the results of MANOVA in table 1. Peak VGRF in the supinated group was 14% more than other groups, though it was not significant. ROL in the supinated group was 28% more than normal group and 31% more than pronated group. Peak VGRF and ROL in three groups are presented in Figure 2 and Figure 3 respectively.

Table 1: mean and Std. for peak VGRF, ROL in supinated, pronated and normal groups and the results of MANOVA,* significant at p level of 0.05

Parameter	***group***	***Mean ± Std.***	$F_{2,22}$	***P***
Peak VGRF (N)	Pronated	30.20 ± 4.60	2.63	0.09
	Supinated	34.80 ± 5.50		
	Normal	30.10 ± 2.60		
ROL (N/ms)	Pronated	327.60 ± 31.90	15.55	0.00*
	Supinated	468.00 ± 93.00		
	Normal	338.20 ± 13.20		

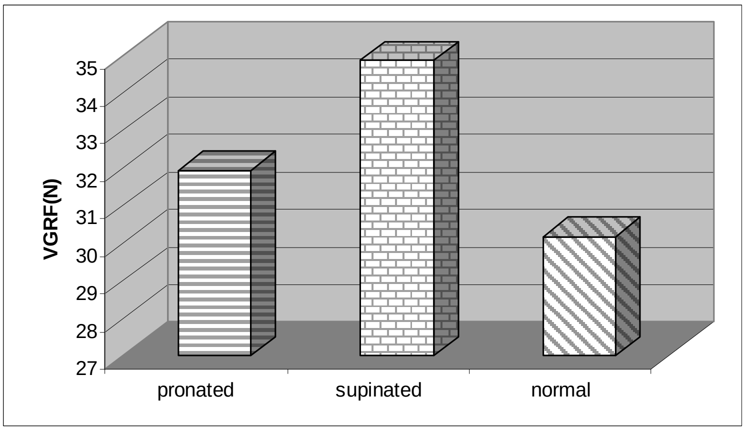

Figure 2: mean and Std. for peak VGRF in supinated, pronated and normal groups

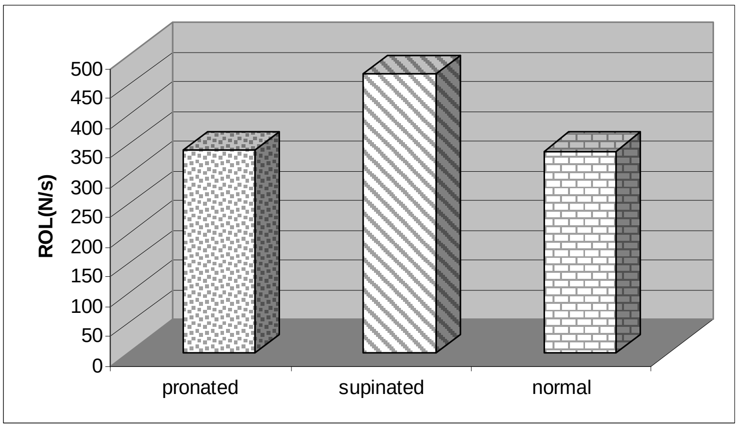

Figure 3: mean and Std. for ROL in supinated, pronated and normal groups

DISCUSSION

The aim of this study was to examine the differences in peak VGRF and ROL between supinated and pronated and normal foot during single leg drop-landing. Our primary finding was that peak vertical forces during a single-leg drop landing were not different among subjects as a function of ND scores. Hence, although excessive pronation is thought to play a critical role in shock absorption and injury risk, our finding suggests that differences in ND do not substantially alter biomechanical function during a landing task. We suspect that there may be several reasons for these findings. Although ND is a valid measure of subtalar motion during gait [14], it may not be representative of actual subtalar motion during landing. Given these findings, more direct measures of dynamic motion are warranted.

To date, the relationship between subtalar pronation and impact forces has been studied in individuals only during running and walking [15-18]. During running and walking, contact is made with the rear foot first, and the foot subsequently goes through a period of subtalar pronation as it progresses into midstance [19, 20]. In landing from the drop jumps, the initial ground contact is made with the forefoot first and the biomechanical sequence of events that follows has not been clearly documented. On the basis of what we know about subtalar motion during gait, the midtarsal joints are typically locked in supination when weight is transferred onto the forefoot [19, 21]. Thus, it may be that full subtalar pronation in a forefoot-to-heel sequence is not the same as in a heel-to-forefoot sequence. Therefore, if subtalar pronation may have critical role in shock absorption during walking and running, our findings suggest that static subtalar pronation do not substantially have significant role in impact force attenuation during a landing task. Devita and Skelly (1992) noted that the ankle plantar flexors and the knee extensors were the muscle groups primarily responsible for deceleration during landing, with the ankle plantar flexors becoming more active as knee excursion decreased [5]. The posterior lower-leg muscles would seem to be a more effective and powerful decelerator of, and shock absorber for, the body during this type of landing, which may lessen the impact and relative contribution of subtalar joint in shock absorption during landing [5].

The supinated group has more ROL during landing in comparison of two other groups. The probable reason for increase of ROL in supinated group can be attributed to the shortening of invertors' muscles of the foot in these groups and decrease the ability of these muscles to control pronation of the foot during landing.

Williams et al (2001) reported that persons with supinated foot are susceptible for knee and shank injuries, because of increase in ROL [1]. Although previous investigations on foot deformities have focused primarily on gait and running, yet our results about ROL in supinated foot is similar with previous investigations. It can be explanatory to this topic that increase of ROL in supinated foot secondary can increase the shank and knee ROL during landing and pose these subjects at risk of knee and shank injuries.

Several papers have suggested a link between the pes planus foot type and aberrant foot function. The point at which the GRF acts upon the foot (i.e. the center of pressure) is medially deviated in pes planus feet [22]. Additionally, pes planus feet have been associated with several foot and ankle deformities (e.g. posterior tibialis dysfunction [23, 24], ankle equinus, and hallux abducto valgus [25], and also with aberrant plantar pressures [26]). This body of work suggests that the distributed GRFs in pes planus feet may differ from neutrally aligned subjects. Neely (1998) reported that pronation unlocks the midtarsal joint and depresses the medial longitudinal arch of the foot, allowing the foot to become flexible and absorb shock during weight bearing [27]. But with regards to our finding, there are not any significant differences in ROL between pronated foot and normal groups. The probable reason for not significant differences between these two groups can be attributed to the differences in landing and running mechanics, as mentioned before ground contact during heel-toe running is normally initiated with the rear foot, whereas ground contact during landing is normally initiated with forefoot. Also landing from a jump can involve forces that are 2 to 12 times the body weight whereas heel-toe running at 4.5 m/s produces forces that are 2.8 times the body weight [2]. Regarding our results it is seems that pronated foot and normal foot have the same kinetics during landing. Our findings, however, are limited to a drop landing, and other dynamic activities that involve full weight acceptance and then push-off (eg. countermovement jumps and cutting maneuvers) may show greater reliance on pronated and supinated foot to dissipate forces.

CONCLUSION

These results suggest that supinated foot is associated with specific lower extremity kinetics. Differences in these parameters may subsequently lead to differences in injury patterns in supinated and pronated foot in athletes. It seems that athletes with supinated foot may benefit from training programs to reduce the VGRF and ROL during dynamic activities like jump-landing.

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