

Ground Reaction Force Comparison Between Barefoot and Shod Single Leg Landing at Varied Heights

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ABSTRACT

Background: Landing is a common movement that occurs in many sports. Barefoot research has gained popularity in examining how shoes alter natural movements. However, it is unknown how a single leg landing under barefoot conditions, as well as landing height, affects ground reaction forces (GRF). **Objective:** The purpose of this research was to examine the differences in GRF during a single leg landing under barefoot and shod conditions from various heights. **Methods:** Sixteen female Division II collegiate athletes, 8 basketball (age: 19.88 ± 0.64 yrs; height: 1.77 ± 0.09 m; mass: 75.76 ± 12.97 kg) and 8 volleyball (age: 20.00 ± 1.07 yrs; height: 1.74 ± 0.08 m; mass: 72.41 ± 5.41 kg), performed single leg landings from 12, 18, 24, and 30 inches barefoot and shod. An AMTI AccuGait force plate was used to record GRF. A 2 (condition) x 4 (box height) x 2 (sport) repeated measures ANOVA was performed to determine any GRF differences. **Results:** There were no significant three way or two-way interactions ($p > 0.05$). There was also no main effect for sport ($p > 0.05$). There were main effects for footwear and box height ($p = 0.000$) where shod (2295.121 ± 66.025 N) had greater impact than barefoot (2090.233 ± 62.684 N). **Conclusions:** Single leg barefoot landings resulted in less vertical GRF than shod landings. This could be due to increased flexion at the joints which aids in force absorption.

Key words: Shoes, Foot, Volleyball, Basketball, Biomechanical Phenomena

INTRODUCTION

The most common force that acts upon an individual is ground reaction force (GRF) and has been used since the 1970s to quantify the external forces that occur during dynamic movements (Logan, Hunter, Hopkins, Feland, & Parcell, 2010; Fu et al., 2017). Landing is a complex task that can be difficult to master as it requires flexibility, coordination, and dynamic muscle control (Louw, Grimmer, & Vaughan, 2006). In sports like volleyball, basketball, and soccer, landing from a jump is an important and unavoidable movement; for example, during a basketball game an individual will average 70 jumps and 70 landings (Schmitz, Kulas, Perrin, Riemann, & Schultz, 2007; Wei et al., 2018; Self & Paine, 2001; Nin, Lam, & Kong, 2016). Landing speed, shoe characteristics, and anticipatory neuromuscular activity have all been known to affect ground reaction forces and impact loading (Fu et al., 2017). As a result, shoe manufacturers began focusing on designs that decreased impact loading through the use of “cushioning” (Fu et al., 2017). However, shoe cushioning and arch support may cause unnatural foot motions, impede positive adaptations to shock absorption, decrease foot

proprioception, and cause limitations that will require the body to compensate (LaPorta et al., 2013; Buhagiar, Shadmi, Schiller, Schwartz, & Woychick, 2018; Hong, Yoon, Kim, & Shin, 2014; Robbins, Waked, & McClaran, 1995). Therefore, an increased focus on reducing cushioning and allowing greater flexibility to simulate barefoot activity has gained popularity, as it may contribute to more natural foot motions (Zech, Argubi-Wollesen, & Rahlf, 2015). Although barefoot activities are a relatively new area of research, barefoot training is becoming increasingly popular (Sinclair, Hobbs, & Selfe, 2015). With kinetic differences seen between shod and barefoot running and quiet standing, footwear may also affect other activities such as jumping and landing (Harry et al., 2015; Zhang, Clowers, Kohstall, & Yu, 2005). Ground reaction forces and muscle activation have shown to be affected by landing height and have led to observations that landing height may influence joint motions and excursions (Arampatzis, Morey-Klapsing, & Brüggemann, 2003).

Depending on the sport and type of landing that is required for a specific situation, different landings might cause varied impact loading intensities, with landing height being a major influence (Wei et al., 2018). Single leg landings

commonly occur during sports that require jumping and landing; however, under barefoot conditions a majority of research has focused on bilateral landings (Schmitz et al., 2007). Knee flexion and muscle activation are common variables tested when examining landing mechanics (Fagenbaum & Darling, 2003). Research has shown that a greater knee flexion that occurs during a landing task helps to alleviate the impact load placed on the knee; in addition, tension in the hamstrings during a landing help to decrease the load on the knee (Fagenbaum & Darling, 2003; Derrick, 2004; Louw et al., 2006).

With the increasing popularity of minimalist footwear and research on barefoot running, there is still little known about how a single leg landing under barefoot conditions, as well as landing height, will affect ground reaction forces. Barefoot single leg landings from a greater range of heights have not been investigated; therefore, this study aimed to answer the following question: will there be a significant difference in barefoot and shod ground reaction forces and what effect will landing height have. Therefore, the purpose of this research was to examine the differences in ground reaction forces during a single leg landing under barefoot and shod conditions from various heights. We hypothesized that impact will be greater during barefoot landing compared to shod.

METHODS

Participants and Study Design

This was a cross-sectional study that was approved by the University Institutional Review Board (IRB 2020-052). Participants volunteered to participate and were required to read and sign an informed consent before participating.

A total of 16 female Division II collegiate athletes, 8 basketball (age: 19.88 ± 0.64 yrs; height: 1.77 ± 0.09 m; mass: 75.76 ± 12.97 kg) and 8 volleyball (age: 20.00 ± 1.07 yrs; height: 1.74 ± 0.08 m; mass: 72.41 ± 5.41 kg), volunteered to participate. Sample size estimation was determined a priori using G*Power (version 3.1.6). Assuming an effect size of 0.29 with an alpha level of 0.05 using a group effect on change in GRF as our primary outcome measure, 16 participants were required per group with 75% power. Participants were required to be current collegiate athletes with plyometric experience. Exclusion criteria included: lower limb pathology within the past six months, non-collegiate athletes, and if they were less than 18 years of age. All participants were physically active and right foot dominant. The dependent variable was GRF and the independent variables were box height, barefoot, and shod.

Materials and Procedures

An AMTI AccuGait (Watertown, MA, USA) portable force plate collecting at 1000 Hz was used to collect ground reaction force. Sixteen-channel Delsys Trigno Electromyography (EMG) system collecting at 2000 Hz was used to collect peak muscle activation in nine leg muscles (rectus femoris, vastus medialis, vastus lateralis, biceps femoris, tibialis

anterior, gastrocnemius medialis, soleus, gluteus maximus, and gluteus medius). MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL, USA) was used to process raw data. IBM SPSS statistics (version 25) was used to analyze the data.

Participants were recruited by word of mouth and were required to read and sign an informed consent prior to participation. Anthropometric data was obtained upon arrival using a manual stadiometer (Detecto, Webb City, MO, USA). Participants completed a 5-minute warm-up on a Monark 874E cycle ergometer (Monark Exercise AB, Vansbro, Sweden) at a self-selected pace. They were prepped with EMG sensors on the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, tibialis anterior, gastrocnemius medialis, soleus, gluteus maximus, and gluteus medius. All EMG sensors were placed on the right leg. After the cycle and prepping, correct landing criteria was demonstrated and explained. Warm-up continued with participants required to perform 3-5 proper practice landing trials from each box height (12 inches, 18 inches, 24 inches, 30 inches) in ascending order. All practice and testing trials were performed on the right leg.

After completing the warm-up and practice trials participants were instructed to perform three single leg landings from each box height in both barefoot and shod conditions. Both teams performed shod conditions wearing their team issued footwear; basketball wore Nike LeBron Witness IIIs and volleyball wore Nike Running Odyssey React Flyknits. They were instructed to stand on the box with their right leg over the edge and to step off and land on the force plate on their right leg without letting the opposite limb touch the ground or aid in balance. They were also told to stick the landing for a three second count before the trial was considered successful. Box height order was randomized (participants blindly chose cards that determined order) while footwear was counterbalanced. Footwear was counterbalanced as a way to limit factors that may affect results. Participants were given 30 seconds rest between landings, 2 minutes rest between box heights, and 2 minutes rest between conditions (Read & Cisar, 2001). The average of the three trials was used for data analysis (Nagano et al., 2007; Koyama and Yamauchi, 2018).

Statistical Analysis

All analyses were performed via IBM SPSS statistics (version 25). A 2 (condition) x 4 (box height) x 2 (sport) repeated measures ANOVA was performed to determine any GRF differences. Pairwise comparisons were performed for any main effects. Kolmogorov-Smirnov and Shapiro-Wilk normality tests were performed and determined normal distribution.

RESULTS

There were no significant three way or two-way interactions for GRF ($p > 0.05$). There was also no main effect for sport ($p > 0.05$). There were main effects for footwear and box height ($p = 0.000$) where shod was greater than barefoot

(Table 1). For box height, 18 inches, 24 inches, and 30 inches were greater than 12 inches ($p < 0.05$); 24 and 30 inches were greater than 18 inches; 30 inches was greater than 12, 18, and 24 inches ($p < 0.05$) (Table 1).

DISCUSSION

The purpose of this study was to examine the differences in ground reaction forces during a single leg landing under barefoot and shod conditions from various heights. It was hypothesized that landing impact would be greater during the barefoot condition compared to shod. The main findings of this study showed that shod condition increased ground reaction forces at all box heights compared to the barefoot condition.

Jumping and landing are common movements seen in everyday life and popular sports including basketball, volleyball, and football; while the forces from these landings can increase up to six times the individuals' body weight (Schmitz et al., 2007; McNair & Prapavessis, 1999). These dynamic movements and the effects they have on the body can be influenced by a variety of factors including the type of landing, landing height, footwear, and more. How shoe cushioning effects the way we move has gained popularity in recent years, beginning with research on how footwear alters running mechanics and has now begun to move towards jumping and landing movements.

Previous studies found that during bilateral landings from 0.3 and 0.6 meters there were no significant differences in peak vertical ground reaction forces between shod and barefoot conditions; there was also no interactions found for landing height and footwear conditions (Yeow, Lee, & Goh, 2011). It was determined that this could be due to greater knee flexion and knee range of motion that was seen during the shod landings, as well as varied landing techniques due to participants being recreational athletes (Yeow et al., 2011). This differs from the current study where the shod condition was found to produce greater ground reaction forces compared to the barefoot condition. Yeow, Lee, and Goh (2009) showed increased abduction angles and increased external adduction moment; however, differences were not seen between landing heights. This led the authors to determine that landing height may not affect joint responses (Yeow et al. 2009). Based on results of the study, Yeow et al. (2009) also suggested that at greater landing heights the hip abductor muscles aid in absorbing the impact that occurs with an increase in GRF. These differences could be due to the style of landing as well as the footwear worn. Similar results were

seen from Tran et al. (2015) who examined bilateral drop landing forces in competitive surfers of varying levels from 0.5 meters. Researchers found significantly lower ground reaction forces during barefoot bilateral landings; determining this may be due to experience and better impact absorbing (Tran et al., 2015; Ball, Stock, & Scurr, 2010). When examining barefoot and shod differences during drop jumps, Koyama & Yamauchi (2018) found that during the shod condition initial ground reaction forces were greater than the barefoot condition from 45 cm. Based on these results it is suggested that drop jump training can be affected by shod or barefoot conditions and that shoes may actually increase the risk for lower limb injuries and impair shock absorption (Koyama & Yamauchi, 2018). The current study also saw increased ground reaction force during the shod condition which could mean that shock absorption was impaired. The researchers also stated that barefoot landing allows the muscles and tendons of the legs and feet to strengthen naturally and allows for shock absorption through the arches of the feet (Koyama & Yamauchi, 2018).

Joints of the lower extremities, during landing, use flexion to control and reduce the momentum that is built (Decker, Torry, Wyland, Sterett, & Steadman, 2003). Slater, Campbell, Smith, and Straker (2015) examined the relationship between force production and lower limb flexion during front and back somersaults and a drop landing from 1 meter; results showed lower peak vertical ground reaction force (vGRF), greater limb flexion, and greater time to peak vGRF during the drop landing. Furthermore, the researchers found that those with greater hip flexion during landing had significantly reduced peak vGRF; increased hip, ankle, and knee flexion was also shown to increase time to peak vGRF (Slater et al., 2015). Based on these results, the researchers determined that time to peak vGRF can be increased and impact forces can be reduced by increased lower limb flexion (Slater et al., 2015). Shultz, Schmitz, Tritsch, and Montgomery (2012) found that during drop jumps and drop landings, shoe wear influenced torsional impedance and stiffness more so than energy absorption. Lower muscle activation, increased knee flexion, decreased ankle dorsiflexion, and decreased vGRF was also found when comparing barefoot and shod (Shultz et al., 2012).

Limitations to the study include a small sample size and only female athletes were tested. An additional limitation was that while each team wore the same shoes the participants as a whole did not wear the same type of shoe. It was also unknown what the age of shoe wear was and information outside of shoe brand was unable to be ob-

Table 1. GRF mean and SD for each box height and condition. Barefoot (BF) and Shod (SH)

Box Height (in)	12	18	24	30	AVG
BF GRF (N)	1820.77 ± 343.22	1982.40 ± 344.43	2182.01 ± 326.31	2375.71 ± 281.27	2090.22 ± 380.41
SH GRF (N)	1913.38 ± 406.89	2217.72 ± 383.40	2404.95 ± 272.71	2644.44 ± 400.55	2295.12 ± 450.45*
Mean ± SD (N)	1867.08 ± 79.65	2100.06 ± 78.50 ^b	2293.48 ± 68.01 ^{bc}	2510.08 ± 76.23 ^a	

^aSignificantly greater than 12, 18, and 24

^bSignificantly greater than 12

^cSignificantly greater than 18

*Shod greater than BF

tained. Future research should continue to investigate a greater range of absolute heights, as well as heights relative to the individual. Future studies could also test how this condition is affected by gender as males and females naturally have different landing mechanics. Comparing dominant to non-dominant limbs could also be examined in future studies. In addition, performing case studies and having individuals in a program that specifically trained plyometrics barefoot would allow professionals to observe the long term affects.

Strength and Practical Implication of Study

Minimalist footwear and barefoot training are continuing to gain popularity when it comes to strength training and physical activity in general. Information from studies like this could aid in rehabilitation programs, strength/plyometric training, and the future development of footwear. In addition, continued research could potentially aid in reducing injuries that result from improper impact absorption.

CONCLUSION

The current study found that shod GRF was increased compared to barefoot at all heights, these results conflict with previous studies. While kinematic data was not examined, based on previous research, it can be assumed that decreased barefoot GRF could be the result of increased flexion in the lower limbs. Landing experience and athletic ability could have also played a part in reduced GRF as the participants used in the current study were collegiate athletes where landing is a common movement in their sport. Current research conflicts with one another on whether or not landing barefoot can aid in decreasing ground reaction forces; therefore, it is important to continue research in this area.

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