SHOE EFFECTS ON IMPACTS AND MUSCLE RESPONSES IN LOWER EXTREMITY DURING DIFFERENT LANDING TASKS

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The aim of this study was to investigate the effect of basketball shoes on impact force and lower limb muscle activity during landings. Twelve male subjects were requested to wear two types of shoes to execute drop jumps and unexpected drop landings. Ground reaction forces, accelerations of the shoe heel-counter, and EMG signals of five lower-limb muscles were collected simultaneously. During active landing, the intervention of basketball shoe did not significantly change the characteristics of impact force and muscle activity patterns. However, under the condition of related muscles were not being activated properly, the basketball shoe reduced the impacts and decreased the muscle post-activation. This potential effect of footwear may further be developed in preventing sports injury and enhancing metabolic efficiency during landings and/or when fatigued.

KEY WORDS: landing, footwear, impact forces, muscle pre & post-activation.

INTRODUCTION: During two-footed landings, the peak magnitudes of the vertical ground reaction forces have been found to range from 3-7 times body weight (BW) (Gross & Nelson, 1988; McNitt-Gray, 1993). Numerous studies (Dick *et al.*, 2007; Hunter & Torgan, 1983) have reported a close relationship between high impact forces and lower extremity injuries during intensive landings, indicating that the excessive repetitive loading can induce acute injuries, such as sprains, muscle-tendon strains, or even fractures (Beynnon *et al.*, 2005), and overuse damage such as stress fracture and patellofemoral pain syndrome (Borowski *et al.*, 2008). Therefore, the concept of “shoe cushioning” has been suggested to reduce impact loading during athletic activities for 30 years (Aguinaldo & Mahar, 2003; Clarke *et al.*, 1983).

In recent years, a new paradigm concerning the role of impact forces have been provided based on both experiments and modeling (Boyer & Nigg, 2007; Nigg & Wakeling, 2001; Pain & Challis, 2006). The impact force is considered as an input signal into the musculoskeletal system while the soft tissues are regarded as oscillating masses (Nigg & Wakeling, 2001; Pain & Challis, 2006). It has been proposed that changes in muscle activity during landing in locomotion might be responsible for minimizing the magnitude of the soft-tissue vibrations that are initiated at landing phase (Friesenbichler *et al.*, 2011).

With respect to footwear, different shoe conditions can potentially modify the mechanical input into the musculoskeletal system resulting from a given impact situation. However, to date, few rigorous scientific studies have been conducted to investigate the role of footwear during more strenuous landing tasks based on the interaction between the impact force and muscle adjustments (tuning), which may further be utilized in the functional design of footwear. Therefore, the aim of this study was to explore the effect of basketball shoes on (1) the impact force and (b) pre-/post-landing muscle activities during active landings (drop jump) and unexpected drop landings.

METHODS: Twelve male basketball players (age: 23.7±2.7 years, height: 178.3±2.5 cm, mass: 70.1±4.6 kg) with a minimum of 5 years of experience in basketball events were recruited for this experiment. They wore two types of shoes [basketball cushioning shoe (BS) vs. control shoe (CS) without cushioning insoles] to achieve 5 trials of double-leg landing by using a custom-made platform. Two types of shoes that differed in both the forefoot and heel cushioning properties were used in this study. All subjects used size 9 U.S. shoes.

Two landing tasks [drop jump (DJ) and unexpected drop landing (UDL)] and three drop heights (30 cm, 45 cm, and 60 cm) were adopted in the test. For the UDL task, participants were asked to “Stand on the landing platform with arms kept stationary at the side of the

body”. The base of platform was then dropped manually by pulling a metal bolt from its slot to initiate the sudden drop landing movement (Fu *et al.*, 2013). The order in which DJ and UDL were executed, as well as the order in which the shoes were tested, were random.
Ground reaction forces (GRF, Kistler, 1200Hz, Winterthur, Switzerland), accelerations of the shoe heel counter (Biovision, 1200Hz, Wehrheim, Germany), and myoelectric signals for the tibialis anterior (TA), lateral gastrocnemius (LG), rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) muscles (Biovision, 1200Hz) were collected simultaneously.
The main variables discussed in this study for the impact force were peak vertical GRF (F_{Zmax}) and the peak acceleration of the shoe heel counter (a_{heel}); while for muscle activity were the root mean square (RMS) of EMG, which was performed in the interval 50 ms prior to contact to the time of first contact (pre-activation) and contact to 50 ms after initial contact (post-activation). The EMG amplitudes were normalized as a percentage of the highest value recorded during the DJ. A 2 × 2 × 3 (shoe × landing style × height) repeated measures analysis of variance (ANOVA) was used to determine the effects of the shoes and the drop heights on impact performance and muscle activities. Tukey post hoc tests were used to determine individual significant differences. The significant level was set at $\alpha = 0.05$.

RESULTS: Impacts: during the contact phase of DJ, the patterns of the vertical GRF-time curves, as well as the heel acceleration-time curves, in BS and CS conditions were similar. Contrarily, for the UDL, the effect of basketball shoe on the impact forces was a significant decrease in vertical GRF and heel-counter accelerations (Figure 1). Specifically, the ANOVA results showed no main effects of shoe type for the F_{Zmax} and a_{heel} during DJ at all heights. However, the post hoc comparisons showed that the F_{Zmax} and a_{heel} with basketball shoes was significantly lower than that of the control shoes across all three heights in the UDL task ($p < 0.05$) (Table 1).

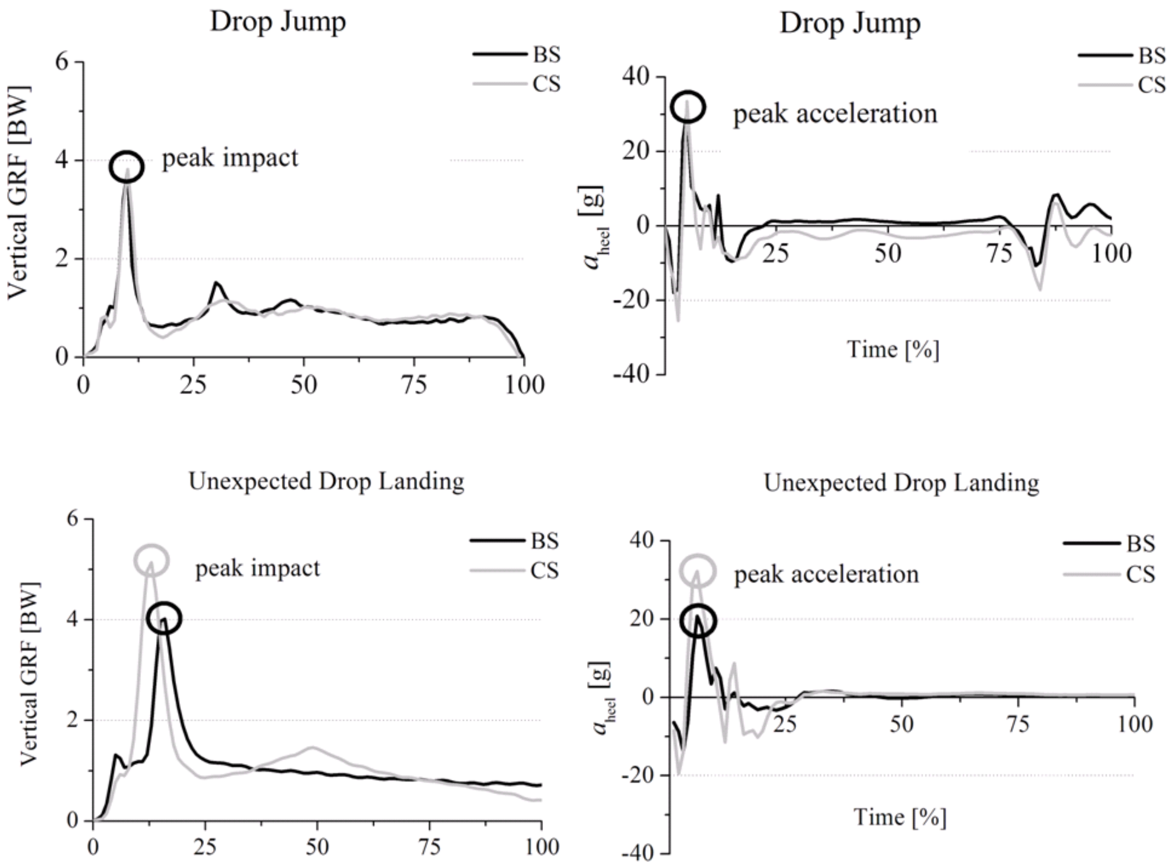

Figure 1: Representative vertical GRF-time and heel acceleration-time curves during the contact phase (time %) of a drop jump and an unexpected drop landing from a 60 cm height in basketball shoe (BS) and control shoe (CS) conditions.

Table 1
The effect of footwear on peak impact (Fz_{max}) and peak acceleration of the shoe heel counter (a_{heel}) during landings.

Variables		Drop Jump			Unexpected Drop Landing		
		30cm	45cm	60cm	30cm	45cm	60cm
Fz_{max} (BW)	BS	2.13±0.51	2.74±0.42	3.59±0.81	**3.29±0.47***	**3.56±0.80***	**4.06±0.71***
	CS	2.17±0.50	2.82±0.80	3.60±0.64	3.90±1.16	4.35±1.02	4.73±0.84
a_{heel} (g)	BS	21.9±4.2	26.9±8.4	29.4±7.2	**22.8±7.9***	**24.8±5.3***	**28.9±7.3***
	CS	24.0±7.6	27.8±8.5	32.7±7.4	28.8±5.7	32.5±9.5	35.8±7.9

Note: BS, basketball shoe; CS, control shoe. * Indicate significant differences between shoes in same height with $p<0.05$.

Muscle pre-activation (-50 ms): For the five muscles tested (TA, LG, RF, VL, and BF), there was no significant shoe effect on the normalized EMG amplitude both during DJ and UDL in all three drop heights. However, what interested us most was a significant decrease in the EMG intensity for the UDL compared to the DJ for the TA, LG, RF, and VL muscles ($p<0.05$).

Muscle post-activation (+50 ms): For the DJ, no significant differences in the RMS of the EMG were observed for any of the tested muscles (Figure 2). However, during UDL, the EMG amplitude of TA, RF, VL, and BF showed a significant decrease for the basketball shoe compared to control shoe from 60 cm drop height except for the LG ($p = 0.086$) (Figure 2). Additionally, on average there was a decrease in the EMG post-activation for the UDL condition compared to DJ.

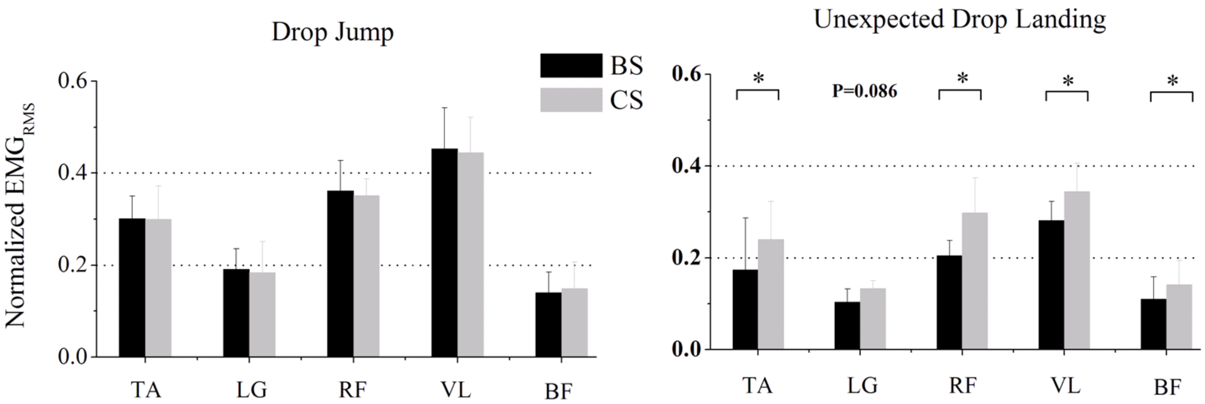

Figure 2: Influence of basketball shoe on the normalized EMG for the five muscles, tibialis anterior (TA), lateral gastrocnemius (LG), rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF), during drop jump and unexpected drop landing from a height of 60 cm. * indicate significant differences with $p < 0.05$.

CONCLUSION: During active landing, the intervention of basketball shoe did not significantly change the characteristics of impact force as well as muscle activity patterns. This suggests that shoe intervention may have limited effects on reducing the impact as an input signal provided neuromuscular adjustments are occurred properly during active movements (e.g. drop jumps and running). However, under the condition of related muscles were not being activated properly, such as in unexpected drop landings, the basketball shoe reduced the magnitude of impact and decreased muscle post-activation. Potentially, this effect of footwear may further be developed in preventing sports injury and enhancing metabolic efficiency during landings or in fatigue.

REFERENCES:

Aguinaldo, A. L., & Mahar, A. T. (2003). Loading in running shoes with cushioning column systems. *Journal of Applied Biomechanics, 19*, 353-360.

Beynnon, B. D., Vacek, P. M., Murphy, D., Alosa, D., & Paller, D. (2005). First-time inversion ankle ligament trauma: the effects of sex, level of competition, and sport on the incidence of injury. *American Journal of Sports Medicine, 33*, 1485-1491.

Borowski, L. A., Yard, E. E., Fields, S. K., & Comstock, R. D. (2008). The epidemiology of US high school basketball injuries, 2005-2007. *American Journal of Sports Medicine, 36*, 2328-2335.

Boyer, K. A., & Nigg, B. M. (2007). Changes in muscle activity in response to different impact forces affect soft tissue compartment mechanical properties. *Journal of Biomechanical Engneering - Transactions of the ASME, 129*, 594-602.

Clarke, T. E., Frederick, E. C., & Cooper, L. B. (1983). Effects of shoe cushioning upon ground reaction forces in running. *International Journal of Sports Medicine, 4*, 247-251.

Dick, R., Hertel, J., Agel, J., Grossman, J., & Marshall, S. W. (2007). Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *Journal of Athletic Training, 42*, 194-201.

Friesenbichler, B., Stirling, L. M., Federolf, P., & Nigg, B. M. (2011). Tissue vibration in prolonged running. *Journal of Biomechanics, 44*, 116-120.

Fu, W., Liu, Y., Zhang, S. (2013). Effects of footwear on impact forces and soft tissue vibrations during drop jumps and unanticipated drop landings. *International Journal of Sports Medicine*, *34*, 477-483.

Gross, T. S., & Nelson, R. C. (1988). The shock attenuation role of the ankle during landing from a vertical jump. *Medicine and Science in Sports and Exercise, 20*, 506-514.

Hunter, L. Y., & Torgan, C. (1983). Dismounts in gymnastics: should scoring be reevaluated? *American Journal of Sports Medicine, 11*, 208-210.

McNitt-Gray, J. L. (1993). Kinetics of the lower extremities during drop landings from three heights. *Journal of Biomechanics, 26*, 1037-1046.

Nigg, B. M., & Wakeling, J. M. (2001). Impact forces and muscle tuning: a new paradigm. *Exercise and Sport Sciences Reviews, 29*, 37-41.

Pain, M. T., & Challis, J. H. (2006). The influence of soft tissue movement on ground reaction forces, joint torques and joint reaction forces in drop landings. *Journal of Biomechanics, 39*, 119-124.

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