

EFFICACY OF SHOES AND BOOTS IN PREVENTING MOTORCYCLE-RELATED ANKLE INVERSION

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The current investigation explored the potential prophylactic effects of shoes, work boots, and motorcycle boots in reducing ankle inversion associated with ankle sprain. While the majority of previous research has investigated the effects of protective equipment in crashes, rates of lower extremity loading in emergency stop contexts are comparable to jump landings and may induce frontal plane loading that could lead to ankle injury. Fifteen adults wore athletic shoes, work boots, and motorcycle boots in a motorcycle drop task. Motorcycle boots significantly ($p = 0.03$) decreased peak ankle inversion angles by 3.6 degrees, but also increased ($p < 0.01$) vertical ground reaction forces by 0.21 bodyweights compared to the other shod conditions. Overall, it is suggested that motorcycle boots can potentially protect motorcycle riders from both crash-based and emergency-stop injuries.

KEYWORDS: sprain, protective clothing, jump, unanticipated.

INTRODUCTION: Recreational on-road motorcycle use presents well-established risk to the rider (National Highway Traffic Safety Administration, 2007). Previous investigations have explored the efficacy of different protective mechanisms, particularly in crash-like situations. Protective clothing, including helmets, body armor, gloves, and boots can alleviate some injury risk (Elliot et al, 2003), although novice riding populations may hold some stigma against their use (de Rome, Ivers, Haworth, Heritier, Du, & Fitzharris, 2011). While head injuries result in the most severe repercussions, leg injuries are much more common (Lin & Kraus, 2009) and have motivated explorations of effective riding shoe and boot design in stabilizing and protecting the foot and ankle in crash-like contexts (de Rome, Ivers, Fitzharris, Du, Haworth, Heritier, & Richardson, 2011; Elliot et al, 2003). However, communications between the current authors, motorcycle safety experts, and high-mileage recreational and sport riders revealed a secondary concern of ankle injury in non-crash situations: Frontal plane ankle instability in sudden stopping and dropping of the motorcycle.

Pilot observations demonstrated anecdotally rapid lower extremity loading and ankle inversion reminiscent of jump-landing actions in sport that risk ankle sprain (Fong, Chan, Mok, Yung, & Chan, 2009). While the rate of loading did not appear to be as rapid as jump landings, the load magnitude associated with the additional weight of the motorcycle may present a risk of ankle injury. Similar to ankle braces and high-top shoes (Ubell, Boylan, Ashton-Miller, & Wojtys, 2003; Ricard, Schulties, & Saret, 2000), motorcycle boots may provide protection from an ankle inversion injury. As such, the current investigation sought to explore ankle and knee kinematics and ground reaction forces during a controlled motorcycle drop. Athletic shoes, inexpensive work boots, and motorcycle boots were contrasted to determine potential efficacy in injury risk reduction. It was hypothesized that the controlled drop would elicit ground reaction force magnitudes and ankle inversion angles associated with ankle injury in sport settings, but the structural design of the motorcycle boots would mitigate ankle inversion to reduce injury risk.

METHODS: Under the approval of the university's Institutional Human Subjects Review Board, fifteen uninjured, recreationally-active college students (14 males, 1 female; 21 ± 1.4 years; 65 ± 6.8 kg; 163 ± 9 cm) with US shoes sizes between men's 9 and 12 were recruited.

After a dynamic warm-up, participants practiced the motorcycle drop task several times before data collection. A 2011 Kawasaki Ninja 650R, drained of all fluids, was positioned such that the participant's left foot naturally landed on an in-ground force platform (1600 Hz, Advanced Mechanical Technology Inc, Watertown, MA, USA) during an unexpected, sudden drop. The motorcycle was suspended by the frame via a weight-rated safety strap on the right side such

that it was near vertical at rest. A quick release buckle, installed in the strap, was released at a random time period, allowing the motorcycle and participant to rapidly tip to the left. A secondary safety strap of longer length paralleled the former to catch the motorcycle and participant in case the participant did not successfully arrest the fall.

The participants were asked to perform this motorcycle drop task in 3 different shod conditions in a counterbalanced order: Wearing self-provided athletic shoes, standardized inexpensive work boots, and standardized racing motorcycle boots. Each participant performed a total of three successful drop task trials for each shod condition. Participants sat on the motorcycle in a normal riding position (feet on the footpegs, hands on the handlebars, looking forward). At an unknown time, a researcher suddenly disengaged the buckle, causing the motorcycle to rapidly tip to the left. The participant arrested this fall by quickly placing their left foot down onto the in-ground force platform.



Figure 1: Work boots (left) and motorcycle boots (right) used in the current investigation.

The 3D kinematics of the drop tasks were monitored via fifteen retroreflective markers placed on the left lower extremity and pelvis, recorded by 8 Vicon MX infrared cameras (Vicon Motion Ltd, Oxford, UK) at 160 Hz through Vicon Nexus (1.8.5). Specifically, markers were placed on the estimated distal 1st pedal phalange, calcaneus at the same height as the former, 5th metatarsal head, medial and lateral malleoli, anterior and lateral mid-shank, medial and lateral femoral condyles, anterior and lateral mid-femur, left and right greater trochanters, and left and right posterior superior iliac spines. Kinematic and kinetic data were subsequently low-pass filtered at 15 and 200 Hz, respectively, via a 4th order, zero-lag Butterworth filter. Cardan-Euler joint angles were then calculated using a planar rotation order of sagittal, frontal, and transverse. Lower extremity joint angles were referenced to neutral standing calibration trials to mitigate marker placement differences in each condition. Peak ankle inversion angles and vertical ground reaction forces (normalized to body weight) were identified within the first 200 ms of landing for each trial. Peak knee valgus angles within this same time period were also identified, to confirm that the shod conditions did not alter kinematics more proximally. These peak measures were averaged across the three trials for each condition. A univariate repeated-measures ANOVA and successive pairwise t-tests were used to test for statistical differences, compensating for a study-wise false discovery rate of 5%. Greenhouse-Geisser corrections were implemented in cases where the assumption of sphericity was violated.

RESULTS: The repeated-measures ANOVA indicated significant main effects for peak ankle inversion angles ($p = 0.030$) and vertical ground reaction forces ($p < 0.001$), but not peak knee valgus angles ($p = 0.256$). As seen in Table 1 below, peak ankle inversion was smaller in the motorcycle boot condition than the work boot ($p = 0.049$) or athletic shoe ($p = 0.045$) condition; these latter two conditions did not significantly differ ($p = 0.500$). Similarly, peak vertical ground reaction forces were larger in the motorcycle boot condition compared to the athletic shoe ($p < 0.001$) and work boot ($p = 0.039$) conditions, and these latter two conditions did not significantly differ ($p = 0.550$).

Table 1: Mean \pm standard error of peak ankle inversion and knee valgus angles, as well as normalized peak vertical ground reaction forces (VGRF) for each shod condition. n = 15

	Athletic Shoes	Work Boots	Motorcycle Boots
Ankle Inversion (°)	18.2 \pm 1.7 A	17.4 \pm 1.3 A	14.2 \pm 1.6 B
Knee Valgus (°)	6.2 \pm 1.6	6.3 \pm 1.6	2.5 \pm 3.1
VGRF (BW)	2.04 \pm 0.19 B	2.08 \pm 0.21 B	2.27 \pm 0.22 A

False Discovery Rate-corrected significant differences ($p < 0.05$) indicated as A > B

DISCUSSION: The current investigation was implemented to determine whether motorcycle boots provide potential protection against ankle injuries in emergency stop contexts where the motorcycle rider must rapidly arrest the motorcycle from falling. The current researchers hypothesized that the motorcycle boots, providing stiffer and taller ankle support than work boots or athletic shoes, would reduce peak ankle inversion. The motorcycle drop tasks indicated that the motorcycle boots did significantly reduce peak ankle inversion angles compared to the other shod conditions, potentially reducing ankle sprain injury risk (Fong, Chan, Mok, Yung, & Chan, 2009). Interestingly, the magnitude of this difference is similar to that reported between high-top and low-top shoes (Ricard, Schulties, & Saret, 2000) and ankle braces (Vanwanseele, Stuelcken, Greene, & Smith, 2014). Also similar to ankle braces, this effect did not lead to proximal alterations (Vanwanseele, Stuelcken, Greene, & Smith, 2014), but this may be due to the larger variability in peak knee valgus angles in the motorcycle boot condition.

All conditions demonstrated unilateral VGRF magnitudes above 2 bodyweights, comparable to jump landing forces (McNair & Prapavessis, 1999). However, the reduction in peak ankle inversion angles in the motorcycle boot condition paralleled a significant increase in vertical ground reaction forces compared to the other shod conditions. It is possible that the motorcycle boots restricted lower extremity range of motion and stiffened the landing, causing an increase in ground reaction forces similar to a lace-up ankle brace during drop-landings (Simpson, Yom, Fu, Arnett, O'Rourke, & Brown, 2013).

The simulated emergency stop used in this investigation does present some limitations. The simplistic reactive nature to this task may amplify indicators of injury risk (Dicus & Seegmiller, 2011) compared to a more frequent emergency stop situation where the rider may more adequately prepare for the stop. This may be a function of adequate temporal muscular control (Konradsen, Voigt, & Højsgaard, 1997). The tested drop task also lacked forward motion, limiting much of the investigated effects to only the frontal plane. It is possible that boots may reduce proprioceptive capabilities (Robbins & Waked, 1998), undermining control in multiplanar emergency stops.

The effects identified in this investigation may not generalize across all makes and models of athletic shoes, work boots, or motorcycle boots, as design differences can sometimes be quite pronounced. Foot movement within shoes and boots, in this investigation and others, can only be assumed; this potential error may be pronounced in heavily-structured boots like those tested in this investigation. Finally, the variety in design of motorcycles can significantly alter total mass and center of mass height. While the authors are confident that the tested motorcycle represented a relative median in these design aspects, loading may be significantly altered with different makes and models. It should also be noted that the majority of participants had some motorcycling experience, but not necessarily with the tested motorcycle or boots; the effects of experience on this paradigm are unknown.

CONCLUSION: The current investigation identified potential benefits of motorcycle boots in protecting riders from increased ankle inversion in emergency stop contexts. However, this effect may parallel increased vertical ground reaction forces. As estimating internal moments about the ankle with boots may be inaccurate, it is unknown whether this kinematic and kinetic combination alters frontal plane moments about the ankle. Nonetheless, it appears that motorcycle boots offer protections beyond obvious crash contexts and the authors suggest all riders wear motorcycle boots and other protective equipment when operating motorcycles.

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