Evaluation of Ankle Range of Motion and Dynamic Stiffness for Human Foot-Ankle Surrogate Design

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Introduction

Lateral ankle sprains and overuse injuries account for 73.6% and 31% of reported lower-limb injuries during military fitness training programs, respectively.[1-3] Repetitive exposure to this injury damages the lateral ligamentous support of the ankle joint and leads to chronic ankle instability in 70% of individuals with history of LAS.[4-6] In 2019, overuse injuries cost the Army more than 8 million duty days. Loss of work due to residual symptoms after LAS can limit the activity of military personnel from 6 weeks to 18 months.[5-7] Military combat boots are tested in a variety of configurations to determine slip resistance, tolerance to heat and cold, sole flexion, and toe compression. However, the current footwear evaluation methodology lacks any ankle-stability assessment. There are existing anthropometric testing devices (ATDs) developed to predict lower limb injury to humans during high-load vertical blast or frontal impacts. These ATDs, however, have not been validated for assessing lower-velocity scenarios observed in LAS and overuse injuries (<120°/s). A human foot-ankle surrogate with the correct ankle joint mechanics and anatomy similar to the human leg would provide an objective measure of the interface between the foot-ankle complex and military issued footwear.

Methodology

Fifty healthy volunteers with no pre-existing ankle problems were recruited for this study. All subjects were 18-25 years old to be representative of the age of incoming service members. Each subject's ankle range of motion was quantified in plantar flexion, dorsiflexion, inversion, and eversion using a Biodex isokinetic dynamometer (Biodex Medical Systems, Inc.). Bilateral dynamic stiffness measurements in plantar flexion, dorsiflexion, inversion and eversion were taken at 5°/s and 60°/s within subject-specific range of motion. The same tests were performed with the THOR ATD leg, a device designed for automotive crash injury assessment. The human subject data was used to define a response corridor for average ankle stiffness and validate the use of the THOR ATD leg in footwear ankle-stability testing methodology.

Results and Conclusions

The THOR leg data was compared to the response of the foot-ankle in men and women (Table 1). These data show that the THOR leg is stiffer than the behavior of the human foot-ankle in inversion and eversion. Since the response of the THOR ATD leg does not appropriately model the response of the human foot-ankle under low-velocity lateral loads, a more biofidelic foot-ankle surrogate should be designed and validated for use in laboratory stability testing methodology appropriate for the evaluation of footwear.

Table 1: Average stiffness response ± SD (Nm/°).

	Inversion	**Eversion**	**Plantar Flexion**	**Dorsiflexion**
THOR	0.13	0.09	0.13	0.15
Male	0.048 ± 0.024	0.057 ± 0.022	0.098 ± 0.065	0.143 ± 0.060
Female	0.019 ± 0.021	0.025± 0.018	0.031 ± 0.032	0.63 0.016

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