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Effects of passive ankle dorsiflexion stiffness on ankle mechanics during drop landings

J.W. Whitting[a,b,*], J.R. Steele[b], D.E. McGhee[b], B.J. Munro[b,c]

[a] Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Canada
[b] Biomechanics Research Laboratory, School of Health Sciences, University of Wollongong, Australia
[c] ARC Centre of Excellence in Electromaterials Science and Intelligent Polymer Research Institute, University of Wollongong, Australia

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Abstract

Objectives: Vertical landing tasks strain the Achilles tendon and plantar-flexors, increasing acute and overuse strain injury risk. This study aimed to determine how passive ankle dorsiflexion stiffness affected ankle mechanics during single limb drop landings at different vertical descent velocities.
Design: Cross-sectional study.
Methods: Passive ankle dorsiflexion stiffness and passive weight-bearing dorsiflexion range of motion (DROM) were quantified for 42 men. Participants were then grouped as having low (LPS: 0.94 ± 0.15 Nm $^{\circ-1}$; $n = 16$) or high (HPS: 2.05 ± 0.36 Nm $^{\circ-1}$; $n = 16$; $p < 0.001$) passive ankle dorsiflexion stiffness. Three-dimensional ankle joint kinematics was quantified while participants performed drop landings onto a force platform at two vertical descent velocities (slow: 2.25 ± 0.16 m s^{-1}; fast: 3.21 ± 0.17 m s^{-1}).
Results: Although affected by landing velocity, there were no significant effects of passive ankle dorsiflexion stiffness, nor any significant ankle dorsiflexion stiffness × vertical descent velocity interactions on any outcome variables characterising ankle mechanics during drop landings. Furthermore, there was no significant difference between the groups for passive weight-bearing DROM (LPS: $43.9 \pm 4.1^{\circ}$; HPS: $42.5 \pm 5.7^{\circ}$), indicating that the results were not confounded by between-group differences in ankle range of motion.
Conclusions: Neither high nor low passive ankle dorsiflexion stiffness was found to influence ankle biomechanics during drop landings at different descent velocities. Landing strategies were moderated more by the demands of the task than by passive ankle dorsiflexion stiffness, indicating that passive ankle dorsiflexion stiffness may not affect plantar-flexor strain during a drop landing.

Keywords: Triceps surae; Flexibility; Tendinopathy

1. Introduction

Ground reaction forces are absorbed rapidly during landings, loading extensor mechanisms of the lower limb such as the plantar-flexor muscles.[1–3] Although different landing velocities, and therefore intensities, can affect lower limb kinematics,[2,4] landing tasks typically require a multi-joint strategy to dissipate the ground reaction forces through the entire lower limb,[5] with the ankle being the first major joint exposed to these external loads. However, dissipating these loads while the plantar-flexor muscle-tendon unit (MTU) is lengthening may expose both the Achilles tendon and the muscle fibres of the triceps surae to the risk of incurring acute and overuse injuries.[6–8] Acute and overuse strain injuries are the most common of all sporting injuries, with Achilles tendinopathies and gastrocnemius muscle strain injuries being among the most prevalent,[6,8,9] particularly in sports involving explosive eccentric movements such as jumping and landing.[7,10,11]

Previous research has shown an association between a low passive dorsiflexion range of motion (DROM) and plantar-flexor MTU strain injuries during movements such as landings that involve ankle dorsiflexion and a concurrent lengthening of the plantar-flexor MTU.[9,12] Biomechanical reasons for this increased risk of injury are not well understood, although reduced DROM has been shown to alter gait strategies of individuals during stair descents, possibly

* Corresponding author.
E-mail address: jwhitting@kin.ucalgary.ca (J.W. Whitting).

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increasing loads about the ankle.[13] Young healthy men with low DROM have also been found to land with their plantar-flexor MTU in a more lengthened position compared to their counterparts with high DROM.[14] Therefore, low DROM may lead to greater plantar-flexor MTU strain during landings.

Passive MTU stiffness is another variable thought to influence plantar-flexor flexibility and provides a measure of stretch resistance.[15,16] Although stretch resistance measures have been used to assess dorsiflexion range of motion,[13] there is some evidence now to suggest that measures of ankle dorsiflexion stiffness and DROM may be poorly correlated and therefore affect ankle biomechanics differently (Whitting et al., 2011 unpublished data). Furthermore, the literature seems divided with respect to possible associations between injury risk and MTU stiffness, or inversely, compliance. Witvrouw et al.[7] postulated that a more compliant Achilles tendon would likely transfer less energy to the adjacent contractile apparatus, providing some protection from muscle strain injuries during lengthening actions. These authors also reasoned that, because more compliant tendons have been linked to better energy return and improvements in stretch shortening cycle performance, a more compliant tendon would be able to absorb more energy before becoming injured.[7] The Achilles tendon, being the largest tendon in the human body,[10,17] is the most substantial tendinous structure in the ankle joint and, not surprisingly, Achilles tendon stiffness has been strongly correlated with passive ankle joint stiffness.[18] Therefore, the conclusions of Witvrouw et al.[7] regarding tendon compliance have strong implications for ankle dorsiflexion compliance and, therefore, plantar-flexor MTU compliance and strain injury risk.

In contrast, research demonstrates that ex vivo Achilles tendons that strained further under an initial load displayed reduced stiffness, and failed sooner and after fewer cycles than stiffer tendons.[19] As such, research also indicates an association between a reduced capacity for tendons and muscles to resist stretch and a higher propensity for structural failure in each tissue, and provides an alternative mechanical explanation for the notion that MTU injury is more a function of strain and not necessarily the magnitude of force.[9,20,21] Although much of the research supporting this notion involves isolated musculotendinous structures, it is reasonable to postulate that a more compliant MTU, displaying low mechanical stiffness, may stretch further under a given tensile load, thereby overloading individual structures as they approach the end of their normal range.[9,17] Accordingly, there is a duality in the evidence, with suggestions that both low and high passive ankle dorsiflexion stiffness (PS) may be implicated in increased injury risk during dorsiflexion movements such as those experienced during landing activities. However, no research has systematically investigated the effects of variations in PS on ankle mechanics during a landing task. Therefore, the purpose of this study was to determine how PS affected ankle mechanics and loading of the plantar-flexor MTU during single limb drop landings at different vertical descent velocities. We hypothesized that individuals with high PS would display significantly less DROM, incur significantly higher ground reaction forces and experience significantly greater plantar-flexor MTU loading during the drop landings, irrespective of vertical descent velocity, than individuals with low PS.

2. Methods

Participants. Forty-two physically active men (mean age = 22.8 ± 5.0 years; height = 180.3 ± 7.8 cm; mass = 75.7 ± 10.9 kg) were recruited from within the campus population of the University of Wollongong to participate in the study and provided written informed consent. Recruits with any contraindications for completing the experimental protocol were excluded. Ethical clearance for the study was obtained from the University of Wollongong Human Research Ethics Committee (HE06/333).

During a familiarization session prior to the day of testing, the test limb was determined by asking each participant to drop from a height of 32 cm onto their preferred landing foot.[14] During testing, the weight-bearing DROM for each participant's test limb was measured goniometrically (Gollehon extendable goniometer: Model 01135; Lafayette Instrument Co., USA) using a standing lunge test.[22] Each participant performed four passive weight-bearing dorsiflexion movements while flexing the knee and maintaining a standardized hip, knee and ankle alignment.[14] The trial that achieved the smallest ankle flexion angle, thereby corresponding to the greatest dorsiflexion angle, was recorded as each participant's DROM angle.[14] Pilot testing of the DROM test involving six participants, unassociated with the present study, performing four trials for each leg on three separate days, revealed a high reliability coefficient irrespective of the leg measured (ICC = 0.97, two-way mixed effects model for consistency of single measures).[14]

Passive ankle dorsiflexion stiffness. PS was measured using a KinCom dynamometer (Kinetic Communicator, Chattecx Corp., Chattanooga, TN). Participants assumed a prone position on the dynamometer bench, with their foot strapped to the dynamometer foot-plate. The lateral malleolus was aligned with the axis of rotation of the dynamometer head and, using the goniometer, the knee was placed in a statically flexed position (10°). The ankle was rotated from 5° of plantar-flexion to their pre-determined stretch limit and participants were instructed to relax their 'calf' muscles and not actively resist the movement. The foot-plate was rotated slowly at a constant velocity of $5^\circ\ s^{-1}$ in order to prevent muscular activation from stretch reflexes.[15,16,23] The slope of the torque-angle curve[16,23] generated between 15° and 20° of dorsiflexion was used to determine PS (Fig. 1).

Analogue data pertaining to the angular position, angular velocity and torque were sampled at 100 Hz directly from the KinCom PC via a National Instruments DAQpad 6015/1016 using MyoResearch XP collection software (Version 1.04.02, Noraxon Inc., Scottsdale, AZ). Electromyography (EMG)