Abstract

The human ankle is a vital joint in the lower limb of the human body. As the point of interaction between the human neuromuscular system and the physical world, the ankle plays important role in lower extremity functions including postural balance and locomotion. Accurate characterization of ankle mechanics in lower extremity function is essential not just to advance the design and control of robots physically interacting with the human lower extremities but also in rehabilitation of humans suffering from neurodegenerative disorders. In order to characterize the ankle mechanics and understand the underlying mechanisms that influence the neuromuscular properties of the ankle, a novel multi-axial robotic platform was developed. The robotic platform is capable of simulating various haptic environments and transiently perturbing the ankle to analyze the neuromechanics of the ankle, specifically the ankle impedance. Humans modulate ankle impedance to perform various tasks of the lower limb. The robotic platform is used to analyze the modulation of ankle impedance during postural balance and locomotion on various haptic environments. Further, various factors that influence modulation of ankle impedance were identified. Using the factors identified during environment dependent impedance modulation studies, the quantitative relationship between these factors, namely the muscle activation of major ankle muscles, the weight loading on ankle and the torque generation at the ankle was analyzed during postural balance and locomotion. A universal neuromuscular model of the ankle that quantitatively relates ankle stiffness, the major component of ankle impedance, to these factors was developed. This neuromuscular model is then used as a basis to study the alterations caused in ankle behavior due to neurodegenerative disorders such as Multiple Sclerosis and Stroke. Pilot studies to validate the analysis of altered ankle behavior and demonstrate the effectiveness of robotic rehabilitation protocols in addressing the altered ankle behavior were performed. The pilot studies demonstrate that the altered ankle mechanics can be quantified in the affected populations and correlate with the observed adverse effects of the disability. Further, robotic rehabilitation protocols improve ankle control in affected populations as seen through functional improvements in postural balance and locomotion, validating the neuromuscular approach for rehabilitation.