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Intermittent Regulation of Ankle Equilibrium and Ankle Impedance during the Running of High-Class Athletes

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***Abstract*— A continuous movement does not mean that the inherent control is continuous; the central nervous system may control consequent movements in an intermittent way. This study presents a continuous motion of the ankle in the steady-state running of high-class athletes and highlights the predictive event-driven regulation of ankle equilibrium and ankle impedance.**

***Clinical relevance*— Information on the intermittent control at the ankle of high-class athletes would be beneficial for mechanical interventions (for example, footwear) that enable faster/economical running by beginner and middle-class runners. The findings would be useful not only for intervention coaching to develop talents but also from clinical and injury perspectives.**

I. INTRODUCTION

The ankle is the critical joint between the leg and the foot that helps to control physical interactions for propulsion, shock absorption, and balance of the body. This study aims to understand the ankle–foot control mechanism unique to the running of an athlete, and investigate the regulation of ankle equilibrium and ankle impedance via changes in the muscle activity and kinematics during performance.

II. METHODS

Four high-class athletes (all males, 32±7.5 years old, 1.73±0.02 m, 61.8±5.2 kg) volunteered for the experiment. The participants were distinct types of runners; a marathon runner, two sprinters, and a soccer player. All participants gave their informed consent before inclusion. This study was approved by the ethical committee of Mizuno Corporation.

The subjects ran on a treadmill for 4 min at a designated speed of 5, 7, 9, 12 km/h. The kinematic data were collected using a motion capture system to measure the ankle angle in a sagittal plane. The electromyography (EMG) data were collected using wireless surface EMG sensors to measure the activity of soleus and tibialis anterior muscles. A US-patented synergy analyzer [1][2] was employed to estimate the equilibrium and mechanical impedance at the ankle.

III. RESULTS AND DISCUSSION

Fig. 1 demonstrates the phase-plane portrait of ankle movements during 15 running cycles at 5, 7, 9, and 12 km/h (representative subject: a marathon runner). The results suggested that the ankle equilibrium and ankle impedance of high-class athletes were regulated intermittently based on the prediction of discrete gait event(s) while the consequent kinematic movement was continuous. The intermittent regulation was remarkable in faster running. The same results were observed for all subjects. Our results reaffirm the significance of the foot-strike and toe-off events at the level of motor commands.

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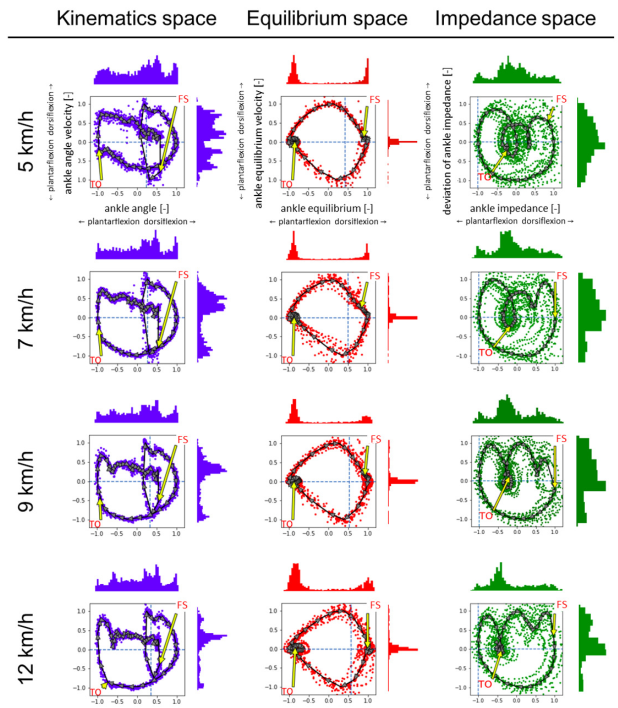

Fig. 1. Phase-plane portrait of ankle movements in kinematics space (left), equilibrium space (middle), and impedance space (right). The histograms in each diagram indicate the frequent occurrence of the state in the corresponding space. The equilibrium is switched intermittently between two zero-velocity-states based on the prediction of the foot-strike (FS) and toe-off (TO) events. The impedance is regulated intermittently based on the prediction of the TO event. The resultant kinematics is continuous under these intermittent regulations.

REFERENCES

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