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学位論文内容の要旨

博士の専攻分野の名称：博士（保健科学）　　氏名：　江　林京

学位論文題名

Research on knee joint function in standing posture control and its application in rehabilitation exercise therapy

（立位姿勢制御の膝関節機能と運動療法への応用についての研究）


**Background:**

Falls among the elderly are a global health problem, causing financial burden, especially in Southeast Asia. Postural control studies have provided valuable information for rehabilitation to avoid falls for older adults and patients with motor disorders. Standing posture is controlled through lower limb joints, with hip and ankle strategies for anterior-posterior (AP) control. However, little focus is given to other directions, such as medial-lateral (ML) or vertical, and the role of the knee in postural control is unclear. This thesis investigates knee joint function in standing posture control, examines the impact of knee flexion on static and dynamic balance, and explores the contribution of the knee to postural control and avoiding falls.

**Materials and Methods:**

This study conducted two cross-sectional randomized experiments to examine the effects of knee flexion on postural sway during static standing balance, and to determine whether this suspensory strategy contributes to postural stabilization. The contribution of the knee to postural control during standing was assessed quantitatively using principal component analysis (PCA).

Study 1: Nineteen healthy young adults participated in this experiment. Participants were instructed to keep three standing postures with knee flexion 0°, 15°, and 65°, respectively. Full-body marker set data for these postures were collected using a three-dimensional motion capture system and Visual 3D was used to calculate center of mass (COM) movements as the postural sway. Time-frequency analysis was used to assess the energy content across frequency bands at offline, and sample entropy was used to evaluate the regularity of the COM displacement patterns. Time-frequency analysis and sample entropy were utilized to clarify the relationship between the sensory input and the postural sway.

Study 2: In this experiment, lateral perturbation tasks with three different velocities were added to Study 1. Eighteen healthy young adults (10 males and 8 females) participated in posture settings and data collection methods identical to those used in

Study 1. Three lateral perturbation speeds (7 cm/s, 15 cm/s, and 20 cm/s) were introduced and participants were instructed maintain their standing or knee-flexed posture before and after perturbations. The displacement and time parameters of the COM under these conditions were measured and used to analyze post-perturbation adjustments included reaction time, peak displacement/time, reversal time, and minimum margin of stability (minimum-MOS) to evaluate postural stability and control.

Study 3: The posture settings and data collection methods were consistent with those of Study 1. PCA was applied to analyze the full-body marker data and extract five principal movements. Qualitative descriptions were provided for these principal movements, and the relative variance and cumulative variance were calculated for each subject to assess the complexity of the structure (i.e., strategy) of the postural control.

**Results:**

Study 1: The COM height during knee flexion lowered significantly compared with that without knee flexion. The highest energy content was occurred at knee flexion 65° in the full frequency band, in contrast to the lowest at 0° in both the AP and ML directions. The ultra-low-frequency band and very- low-frequency band prominence was greater at knee flexion 65° than at 0° or 15° in the ML direction. This suggests that knee flexion increases the balance-related sensory inputs and sensory weights. The sample entropy values were lower at knee flexion 65° and 15° than at 0° in the ML direction and reached the lowest value at knee flexion 65° in the vertical direction.

Study 2: COM reaction times for low and mid perturbation velocities were delayed at knee flexion 65° compared to 0° and 15°. COM reversal times were significantly shorter at knee flexion 65° than at 0° and 15° across all perturbation velocities. Knee flexion 65° resulted in better recovery from perturbations; knee flexion 65°showed a greater risk of falls from the minimal-MOS data, and the minimum-MOS at a high velocity of perturbation was significantly smaller at knee flexion 65° than at 0° and 15°.

Study 3: Ankle and hip joint strategies during knee flexion 0° were the first and second principal movements, respectively. The suspensory (i.e., knee) strategy was observed as the vertical principal movement during knee flexion 15° and 65°. Regarding movement complexity, significant differences in between knee flexion 15° and 65° were observed only for the fourth principal movement component.

**Conclusion:**

Suspensory strategy with knee flexion affects balance control in static and dynamic balance, with slight flexion improving stability, whereas excessive flexion leads to instability. Our findings suggest that the suspensory strategy performed by knee flexion has the special and unique role in the postural control and it is possible to contribute for avoiding serious injuries induced by falls and for decreasing the risk of falls in older adults and patients with motor disorders.