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DYNAMIC STABILITY AND ENERGY EFFICIENCY DURING DIFFERENT SELF-SELECTED WALKING SPEEDS

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INTRODUCTION

It is well documented that a high percentage of falls in older adults occur during walking [1]. Numerous studies have shown relations between changes in gait and risk of falling. Walking speed is generally regarded as a control parameter for human gait transitions. Walking with a preferred gait speed is thought to demonstrate a stable phase relationship and minimum energy expenditure [2]. Motion of the whole body center of mass (CoM) has been used to indicate the mechanical energy expenditure [3] and dynamic stability during gait [4]. Out-of-phase oscillation between kinetic (E_k) and potential energy (E_p) of the CoM allows energy to be exchanged from one to another [3]. The timing of exchanges between E_k and E_p at different walking speeds can provide us a better understanding of energy cost in the elderly. It has been found that CoM motion in the medio-lateral (M/L) direction during gait may have particular importance for balance control [4,5]. However, age related differences in the M/L dynamic stability during varied walking speeds are still unknown. Therefore, the purpose of this study was to quantify the relationship between dynamic stability and energy efficiency in three different walking speeds in young and elderly adults.

METHODS

Thirteen healthy elderly adults without neurological or musculoskeletal impairment (6 males and 7 females; 74.7± 5.0 years; 165.4 ± 8.9 cm; 69.4± 11.8 kg) and eighteen healthy young adult subjects (9 male and 9 female; 25.2 ± 4.2 years; 172.6 ± 7.7 cm; 74.4 ± 10.5 kg) were recruited for this study. Subjects were asked to walk with barefoot over level ground along a 10-m walkway. The first condition was their preferred walking speed, and then a distinctly self-selected faster speed followed by a distinctly slower gait.

Whole body motion analysis was performed with a 6-camera ExpertVision™ system (Motion Analysis Corp., Santa Rosa, CA). Three-dimensional marker trajectory data were collected at 60 Hz. Twenty-seven reflective markers were placed on bony landmarks of each subject. Whole body CoM position data was calculated as the weighted sum of 13 segments representing the whole body. Linear velocities of the CoM were calculated with the GCVSPL algorithm. The center of pressure (CoP) position was calculated from the ground reaction forces/moments collected from two force platforms (AMTI, Watertown, MA). Instantaneous sway angles in the sagittal and frontal planes were defined as the angle between the inverted pendulum, defined by the CoP and CoM, and the vertical line (Fig.1). Timing offsets between E_k and E_p were calculated during single stance phase. Effects of subject group and walking speed on CoM sway angles and energy exchange times were assessed using a two-factor ANOVA with repeated measures of walking speeds.

RESULTS AND DISCUSSION

Elderly adults walked significantly slower than young adults for all 3 conditions (preferred, fast, slow: 1.2/ 1.4 m/s, 1.5/ 1.7 m/s, and 0.9/ 1.2 m/s; $p<0.001$). Also, significant group and walking speed effects were found in the max. A/P sway angle and stride length. As the walking speed increased, stride length and max. A/P sway angle increased in both groups. Elderly adults showed a more conservative strategy to control body movement in the A/P direction using a shorter stride length ti maintain a smaller A/P sway angle than young adults. This finding was similar to other studies [6,7]. Neither significant walking speed effects nor significant group differences were found in the max. M/L CoM sway angle and step width. However, timing offsets between E_k and E_p of elderly adults were found to be significantly greater than that of young adults during self selected slower walking speed (81.2 ms vs.56.8 ms; $p=0.038$) (Fig 2).

These findings show that in both groups, decreasing walking speed does not cause greater M/L body movements during gait. The M/L sway angle defined in this study might be a walking speed-independent indicator for dynamic stability. Greater timing offsets between E_k and E_p of elderly adults during slower walking indicate less efficient in the energy transfer. Inefficient energy transfer during gait would require additional energy to be provided from lower extremity muscles [8,9]. Elderly adults walk with a slower speed may require excessive muscle co-contraction or an increase in muscle tone to compensate the inefficient gait. However, this extra energy consumption might be necessary to avoid any dynamic instability.

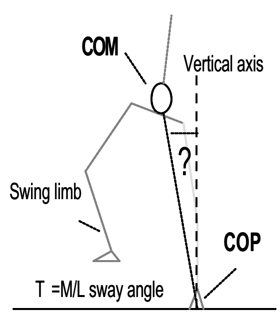

Figure 1: M/L sway angles defined by the CoP and CoM

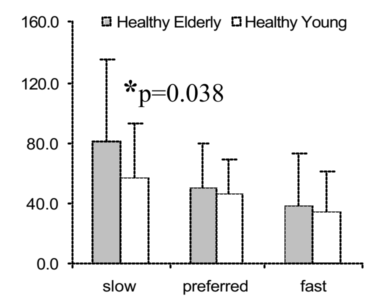

Figure 2: The energy exchange time (msec) in three different walking speeds

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