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Original Article

Gender differences in Intra Limb Coordination while walking in older people

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Objectives: Knowledge about gender differences in intra-limb coordination during walking provides insight into the adaptability of central nervous system for controlling gait in older adults. We assessed the variability and phase dynamic of the intra-limb coordination in older men and women during walking .

Methods: Twenty two older people, 11 female and 11 male, participated in this study. They were asked to perform walk on a treadmill at their preferred speed. Deviation phase and mean absolute relative phase values -indicators of variability and phase dynamic of intra-limb coordination, respectively- were calculated using the data collected by a motion capture system. We used independent sample t-test for statistical analysis .

Results: The results showed that women had a significant higher deviation phase in pelvis-thigh inter-segmental relationships on both sides. Additionally, the mean absolute relative phase of left pelvis-thigh, thigh-shank and shank-foot were significantly different between men and women .

Discussion: While women showed a lower mean absolute relative phase in pelvis-thigh, men had a lower mean absolute relative phase in shank-thigh inter-segmental relationships. We suggest that gender could affect the intra-limb coordination variability and phase dynamic during walking in older people. This may be a reflection of the great adaptability of neuromuscular system to modify control strategies for walking in older women/ men.

Key words: Intra-limb coordination, Continuous relative phase, gait, gender, elderly

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Introduction

Falls and their possible consequences such as fractures, hospitalizations, fear of falling and loss of independence are important public health concerns among elderly people. In addition they may impose high costs on public health and social services (1-6). Falls are more prevalent in older women than men (7,8). Women report higher functional limitations and fear of falling and have lower levels of physical capability as compared with men (9). However, the unintentional consequences of falling differ between men and women. Adjusted for age, mortality of falls are lower among women (10). Therefore, knowledge about the factors contributing to falls and exploring the factors that may differ between women and men could be critical to fall prevention and intervention.

More than 50% of falls in older people happen during walking (10). Examining gait, particularly gait differences between women and men, may provide information about different mechanisms of falling contributing in fall-related injuries and mortality of falls among older women and men. Gait and mobility differences between men and women are well reported (11-17). According to the findings of previous studies, women generally walk with shorter strides and higher cadences than men (11,15). Moreover, it has been shown that men experience greater decreases in maximum and comfortable gait velocities as they are aged over 65 years. Additionally, compared to women, men have a stronger relationship between the lower limb strength and gait velocity (18-20). Furthermore,

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during dual task walking, men walked with greater Variability in walking speed than did women (21). While several studies have focused on comparing spatial and/or temporal gait parameters in men and women, higher order parameters e.g. intra-limb coordination (ILC) is not considered into account yet. ILC is defined as ‘the ability to assemble and maintain a series of proper relations between joints (inter-joint) or segments (inter-segment) within a limb, organized in a timed and sequential manner, to produce a functional movement’ (22,23). It is a fundamental issue in human gait control especially for controling a precise foot trajectory. By relating motions of two segments, ILC provides information on how the neuromuscular skeletal system controls the redundant degrees of freedom (DF) of the joints for achieving an efficient, smooth and accurate movement (23-28) Exploring ILC while walking provides insight into the manner in which CNS controls human gait. Particularly, ILC variability indicates the adaptability of the neuromuscular system to changing walking conditions (22,23,25-27,29,30).

According to the above review, the aim of the present study was to address the gender differences in ILC of lower extremities during walking in older adults. We hypothesised that older women may show higher ILC variability in pelvis-thigh ILC compared to older men.

Methods

Participants- Eleven older women and eleven older men (age 27.03±4.42) took part in the study. All participants had no history of orthopaedic, neurological, cardiopulmonary, rheumatologic disorders or history of limb joint surgery or vertigo. The Human Research Ethics Committee of the relevant university approved the study and all of the tests were conducted in the Musculoskeletal Rehabilitation Research Center. A written informed consent was obtained from each participant prior to participation.

Walking tasks- Participants were asked to walk on treadmill with their preferred speed. The preferred speed of walking was determined for each participant prior to the main testing by asking the participant to walk on the treadmill commencing at 1 km/h with speed increased by 0.5 km/h increments until they reported preferred or ‘‘comfortable’’ pace. When the participant first indicated his/her preferred speed the treadmill velocity was again increased and decreased in 0.5 km/h intervals and the individual asked to reconfirm the speed preference (31). The use of a self-selected comfortable pace ensured that any potential discomfort that could have been introduced by using a pre-determined speed for all subjects was minimized. For each walking condition, the data were collected during a 90-second period of walking.

Data collection- After each participant became familiar with the laboratory setting with several practice trials, data collection started. Twenty-four infrared-retroreflective markers were placed on the wrist, lateral humeral epicondyle, acromion process, tempromandibular joints, posterior superior iliac spine, greater trochanter, lateral femoral epicondyle, head of fibula, lateral malleolus, 5th metatarsal base and heel, bilaterally, and two additional markers on 7th cervical and 12th thoracic vertebrae. Kinematic data were measured by 7-camera motion capturing system (Qualisys, Inc.) at a sampling rate of 100 Hz.

Intra-limb coordination analysis- All kinematic data were filtered using a bidirectional, fourth-order, low pass Butterworth filter. Optimal cut off frequencies for each marker and trial data were determined using residual analysis method. The events of heel strike and toe-off were detected by examining the position of the foot during the test. Since changes due to walking speed in lower extremity kinematics are mostly dominant in the sagittal plane (27,30), we only examined the sagittal plane ILC relationships. A custom-written MatLab (MathWorks Inc.) program was used to filter the data and calculate the continuous relative phase (CRP) values. Since it has been reported that asymmetries are more readily detected by using segmental angles compared with joint angles (27), we used the ILC relationships between segments rather than joints to calculate CRP values. Sagittal plane segment angles (relative to horizon) of lower extremities were calculated bilaterally for foot, shank, thigh and pelvis segments. Due to missing markers in some trials, output variables could not be determined for all gait cycles. Therefore, 15 successive and complete gait cycles in the middle of the test time were used for all CRP analysis.

Sagittal plane segment angles were truncated on a stride-by-stride basis and interpolated to 100 points across the time of each complete gait cycle. To confirm the application of phase planes and dynamic system assumptions, that require the time series to be like sinusoid signals, an empirical mode decomposition algorithm was applied (26). Segment angles were first decomposed into empirical modes (sinusoid signals) with different frequencies. Then the time series data were reconstructed using all empirical modes except the lowest frequency which was not assumed satisfactory with the sinusoid assumption. Segment angular velocities were calculated using a central difference method.

CRP was calculated by first generating phase portraits normalized to the maximum velocity. Normalization was conducted on a stride-per-stride basis. Angular position and velocities in each gait cycle were first normalized using the following equations:

$$\theta_{i\_normal} = \frac{2\times[\theta_i - \min(\theta_i)]}{\max(\theta_i)-\min(\theta_i)} - 1, \quad i = 1...100 \qquad \omega_{i\_normal} = \frac{\omega_i}{\max(abs(\omega_i))} \quad i = 1...100 \qquad \text{Eq. 1.}$$

Where θ_i and ω_i are the angular position and velocities for each of 100 interpolated data points during a complete gait cycle. Eq. 1 normalizes phase portraits to ± 1 along the position axis and to +1 or -1 along the velocity axis, depending on where the absolute maximum velocity occurs. The normalization would minimize individual differences in amplitude and frequency (24) and centers the phase plot about an origin. Then, phase angles (φ) were calculated as $\varphi_i = \tan^{-1}(\omega_i / \theta_i)$ for each data point over a gait cycle and unwrapped to correct discontinuities occurred during angle calculation (29,32). The CRP in point of normalized gait cycle was calculated by subtracting the phase angle of distal segment from that of proximal segment $\varphi_{pelvis\text{-}thigh}$, $\varphi_{thigh\text{-}shank}$, $\varphi_{shank\text{-}foot}$ in that point. The magnitude and variability of ILC were assessed with mean absolute relative phase (MARP) and deviation phase (DP). MARP and DP are the average values of all mean and standard deviations, respectively, calculated for each data point over a gait cycle from all 15 CRP curves. MARP accounts for the amount of intra-limb coordination. A low MARP value indicates that the oscillating segments have a more in-phase relationship while a high MARP value indicates that the oscillating segments have a more out-o-phase relationship. DP represents the stride to stride variability and compares the systemic kinematic level coordination characteristics over a gait cycle. So, higher DP indicates more changeable coordination between two adjacent joints (29).

Statistical analysis- All variables were examined for normality. We used independent sample t-tests to compare the measured values between men and women. All statistical analyses were performed with the SPSS 19.0 (SPSS Inc., Chicago, IL).

Results

Descriptive statistics of the participants including age, height, weight, and BMI are shown in table (1).

Table 1. Descriptive characteristics of participants

Characteristics	Mean±SD	
	Female (n=11)	Male (n=11)
Age (years)	63.27 ± 2.83	66.45 ± 5.83
Height (m)	1.55 ± 0.06	1.66 ± 0.05
Weight (kg)	67.20 ± 12.25	76.23 ± 11.93
BMI (kg/m^2)	29.14 ± 4.16	27.45 ± 3.41

** N: number of people; SD: standard deviation; BMI: Body Mass Index.*

Results of independent sample t-test showed significant differences in mean of DP in right and left pelvis-thigh ILC between men and women (p=0.007 and p=0.002, respectively). Figure (1) presents the comparison of mean differences of DP in right (A) and left (B) pelvis-thigh ILCs in between men and women.

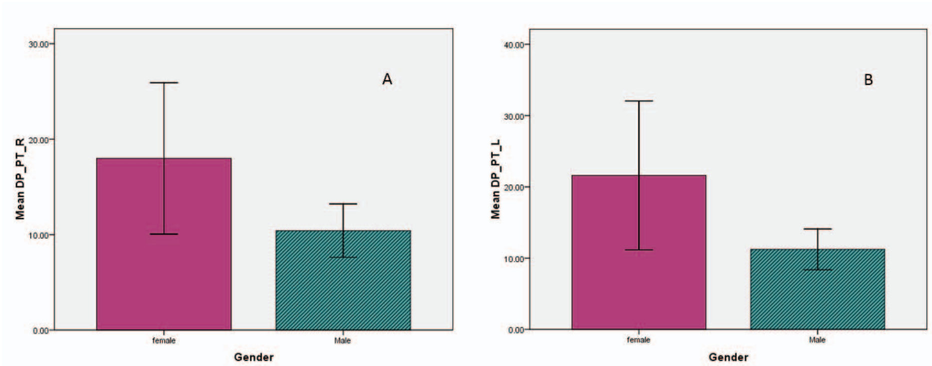

Fig 1. Comparing the means of deviation phase (DP) in right pelvis-thigh (A) and left pelvis-thigh (B)

Moreover, the MARP in left pelvis-thigh, thigh-shank and shank-foot ILC between men and women (p= 0.016, p= 0.007 and p= 0.025, respectively). The comparisons of mean differences of MARP in the aforementioned ILCs are shown in Figure (2).

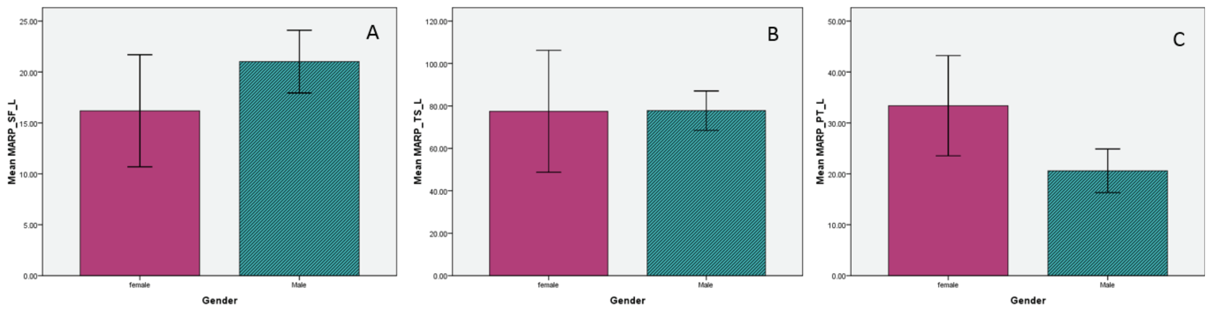

Fig 2. Comparing the means of mean absolute relative phase (MARP) in left shank-foot (A), thigh-shank (B) and pelvis-thigh (C).

Discussion

In this study we investigated the gender differences in variability and phase dynamics of ILC of lower extremities in older people during walking at preferred speeds. We hypothesized that the variability of ILC during walking will be affected by gender and our results support this hypothesis. Novel to our study, we found that the variability of ILC for pelvis-thigh inter-segmental relationship is higher in women than men. Since decreased ILC variability reflects limited degrees of freedom during a motor task (26, 29), it may be a possible risk when people confront perturbations during activities of daily living. It is especially important for older adults who commonly rely on hip strategy rather that ankle strategy when they are perturbed (28, 32). Thus restricted pelvis-thigh ILC variability in older man compared to women may put older male adults at a higher risk for falling during activities of daily living.

Furthermore, our results showed that there are unilateral MARP differences between women and men. Interestingly men showed lower MARP values at shank-foot inter-segmental relationship while women showed lower MARP values in pelvis-thigh. Lower MARP indicates a more in-phase behaviour of these inter-segmental relationships (33). The in-phase dynamic of ILC reduces the control effort necessary for motor control (29). Thus, may be because of the more variable coordination in pelvis-thigh, women reduce their control effort by changing the phase dynamic of pelvis-thigh while men reduce the effort by altering shank-foot phase dynamics.

In order to analyse CRP, we needed numerous continuous gait cycles (33). According to our laboratory facilitates it was only possible by asking the participants to walk on a motorized treadmill. Another advantage of using the treadmill was that we could control the speed during cognitive task and observe the net effect of simultaneous cognitive task on gait parameters. On the other hand, it was also a potential limitation of our study since treadmill strictly enforced walking speed and may artificially change the natural variability and attentional demands of gait, compared to over-ground walking (34). However, all participants were tested under the same experimental conditions and relative to their own cognitive load and walking speeds. Therefore, over-ground walking may yield slightly different values for the quantified measures. Secondly, we only assessed the ILC in the sagittal plane, because this is the primary plane of motion in which the ILC is expected to be controlled during gait. We suggest that the future studies evaluate the effects of different fall preventive and interventional strategies considering gender differences found in ILC of lower extremities.

Conclusion

This study demonstrated that in elderly people, gender can significantly alter the variability and phase dynamics of ILC of lower extremities during walking. These differences may be an indicative of different control mechanisms that men and women adopt to control their walking. They may also help the rehabilitation staff to recruit gender-specific interventions to prevent falls in older people.

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