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Original Article

Gender Differences in the Biomechanical and Physiological Properties of Gait in the Older Adults

Hwang-Jae Lee [a,b †], Dong-Sung Choi [a,c †], Seung Yeol Lee [a], Won Hyuk Chang [a], Youngtaek Kim [d], Yun-Hee Kim [a,b *]

[a] *Department of Physical and Rehabilitation Medicine, Center for Prevention and Rehabilitation, Heart Vascular Stroke Institute, Samsung Medical Center, Sungkyunkwan University School of Medicine,* [b] *Department of Health Sciences and Technology, Samsung Advanced Institute for Health Science and Technology (SAIHST), Samsung Medical Center, Sungkyunkwan University,* [c] *Center for Sport Science in Daegu,* [d] *Division of Infectious Disease Control, Center for Infectious Disease Control, Korea Center for Disease Control, MOHW*

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SUMMARY

Background: The purpose of this study was to investigate gender differences in gait parameters, muscle activation of the lower limbs, and metabolic energy cost during walking in olderadults.
Methods: Twenty-four subjects walked on a 10 m level walkway as self-selected speed while barefoot. A six-camera motion capture system was used to record the gait parameters. Wireless electromyography was used for the measurement of muscle activity. Next, the subjects were equipped with a mask connected to a computerized portable metabolic system. The subjects walked on a motor-driven treadmill in two different walking speeds.
Results: Walking speed was significantly higher in older men than in women. Stride length was also significantly higher in older men than older women. Older men had significantly higher step lengths the right and left sides than did older women. In the stance phase, muscle activation of the external oblique and erector spinae was significantly higher for older women than for older men. The absolute value of VO_2 (ml/min) of older men was significantly higher at the self-selected speed and for the 30% increased speed than those of older women.
Conclusion: These gender-related differences should be considered during gait training and rehabilitation in older adults.

1. Introduction

Aging is related to decreases in skeletal muscle strength and muscle mass, collectively referred to as sarcopenia.[1] Sarcopenia is accompanied by decreased ambulatory ability, loss of independence, increased fall incidence, and decreased quality of life.[2–5]

Walking ability is very important for maintaining independence in activities of daily living, enjoying social interactions, and retaining a healthy level of emotional vitality, which are the main factors that affect quality of life, particularly for the elderly.[6] Walking characteristics of the older adults include short steps and stride lengths, slow speeds, reduced joint angles, and mechanical plasticity, caused by age-related changes in the neuromuscular system.[7–10] Most previous studies have directly compared the walking characteristics of young people to the walking characteristics of the older adults.[11–13] However, physical characteristics differ according to sex. Some of these sex-related differences manifest during walking[14] and thus influence rehabilitation treatment. Finally, gait differences between the sexes are of interest in a variety of clinical rehabilitation settings.[15]

Gender-specific differences in gait parameters, kinematics, kinetics, and physiological variables during level-surface walking have been reported in both young and older adults.[16–20] Several studies[17,19–21] have found that women walk with a higher cadence, shorter step width, greater joint range of motion in the frontal and sagittal planes, increased peak hip adduction angle and moment, as well as increased internal rotation moment compared to men. Another study[22] reported that the rate of surface electromyography (sEMG) rise in the quadriceps muscles in women was less variable and had a lower magnitude compared with that of men. A different study[18] found the relative of value VO_2 (ml/kg/min) to be greater in women than in men when walking on a treadmill. Thus, previous studies have compared the characteristics of walking in older men and women to those of their younger counterparts.

However, few studies have investigated sex-specific differences in the walking characteristics of the older adults. Further, studies relating to gait parameters, muscle activation, and metabolic cost of sex-related differences in older men and women are also lacking. The metabolic cost of movement has been linked to a number of anthropometric and kinematic variables that differ between men

* Corresponding author. Department of Physical and Rehabilitation Medicine, Center for Prevention and Rehabilitation, Heart Vascular Stroke Institute, Samsung Medical Center, Sungkyunkwan University School of Medicine, #81 Irwon-ro Gangnam-gu, Seoul, 135-710, Republic of Korea.
E-mail addresses: yunkim@skku.edu, yun1225.kim@samsung.com (Y.-H. Kim)
Co-corresponding author: Division of Chronic Disease Control, Korea Center for Disease Control, MOHW, 187 Osongsaengmyeing2(i)-ro, Osong-eup, Heungdeok-gu, Chungcheongbuk-do, Korea, 363-700.
E-mail: ruyoung02@gmail.com (Y. T. Kim)
† Both authors contributed equally to this work.

and women.[18] These variables include factors such as body mass distribution,[23] physical size,[24,25] stride length, cadence,[26] and joint range of motion.[19] If these elements are explained, the characteristics of walking according to the sex in the older adults can be systematically presented. Therefore, the purpose of this study was to investigate gait parameters, muscle activation of the lower limbs, and metabolic energy cost during walking in older men and women. Furthermore, we hypothesized that there will be gender differences in biomechanical and physiological properties during gait in the elderly.

2. Methods

2.1. Participants

Twenty-four active and healthy older men and women aged 65 years of age or older participated in this study (Table 1). The participants were selected using a questionnaire concerning general health conditions and musculoskeletal, neurological, and cardiovascular disorders. The exclusion criteria for the study were any mental, physical, or sentimental limitations, other than those related to healthy aging, which would prevent the participants from taking part in normal walking activities under the experimental protocol. In addition, participants who had sustained any injuries to any musculoskeletal region in the three months prior to data collection or who reported any other conditions that might affect the way they walked were excluded. All participants provided informed consent prior to participating. The Institutional Review Board of Samsung Medical Center approved all experimental procedures.

2.2. Experimental design

During the first session, surface electrodes were attached to the participants' lower limbs in order to assess muscle activation during gait; 19 reflective markers were placed on lower limb segments for analysis of gait parameters. Next, participants performed level walking on a 10-m walkway, and walking speed was self-selected while barefoot. All participants completed five good trials, which were averaged for each individual for comparisons of sex. Next, the participants were equipped with a mask connected to a computerized portable metabolic system (Cosmed K4b^2, Rome, Italy) that they carried on their backs, and oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured during each breath. All participants wore comfortable walking shoes. These measurements were performed while the participants walked on a motor-driven treadmill (GOLDONE, Any Fitness, Korea) at two different speeds (a self-selected speed and then a 30% increased speed). Participants were thoroughly familiarized with treadmill walking at all the speeds until the investigator was satisfied that they were comfortable performing the activity. During the measurement trials, the speed was selected by the participant, and then that speed was increased by 30% for the next trial. Both conditions were measured 6 minutes, and 5 minutes of rest were implemented between trials. The same measurements were performed for all participants.

2.3. Measurements

Fifteen reflective markers (20-mm-diameter spheres that were covered with retro-reflective tape) for Helen-Hayes marker sets were placed on the foot (lateral malleolus and second metatarsal head of both lower limbs), shank, thigh, lateral knee joint and pelvis (anterior superior iliac spine of both lower limbs and S2 between the skin dimple) to define limb segments for the analysis of three-dimensional kinematic and gait parameters.[27] A standing static position was recorded with four additional markers defining anatomical segment coordinate systems, with origins at the ankle and center of the knee joint. These additional markers were placed on the medial malleolus and the medial epicondyles. After recording marker positions for the static trials, these additional markers were removed, and the 15-marker configuration was used for the subsequent motion trials. Participants completed three static trials in a standing position and five successful 10-m walking trials. Kinematic data (cadence, gaitspeed, step width, stride length, step time) were collected using a six-camera motion capture system (Motion Analysis Corporation, Santa Rosa CA, US) at a sampling rate of 60 Hz. EVa Real-Time Software (EVaRT, Motion Analysis Corporation, Santa Rosa CA, US) was used for real-time motion capture and for post-processing and tracking of the marker data.

For the measurement of muscle activity in the trunk and lower limbs, 12-channel wireless electromyography (Noraxon, Scottsdale, AZ, US) was used. Before the sEMG electrodes were attached, the lower limb was shaved and cleaned with a cotton swab that had been soaked in alcohol. Surface electrodes were attached to the rectus abdominis, external obliques, erector spinae, multifidus, gluteus maximus, gluteus medius, biceps femoris, adductor longus, rectus femoris, vastus medialis, tibialis anterior, and gastrocnemius medialis muscles of the right side.[28] The sEMG signals recorded by the surface electrodes were amplified, digitally sampled at 1,000 Hz, and saved on a computer using Myoresearch XP software (Noraxon, Scottsdale, AZ, US, 1998). The recorded raw sEMG data were analyzed for level of muscle activation using the Myoresearch XP (Noraxon, Scottsdale, AZ, US, 1998) program. The recorded data were pre-processed with notch filtering at 50 Hz to remove any noise and then band pass-filtered between 10 and 450 Hz. Next, the data were full-wave-rectified, and the root mean square (RMS) values of the sEMG signals were assessed.

Measured oxygen was used to determine the metabolic rate according to indirect calorimetry. Participants wore a facemask, which passed their expired air into a portable automated analyzer worn across the torso. The analyzer was calibrated prior to each testing session in order to ensure that it provided accurate, breath-by-breath data that were sent via telemetry to a computer. On a previous visit, participants were thoroughly familiarized with treadmill walking at various speeds until the investigator was satisfied that they were comfortable. Typically, this familiarization period lasted for 5 min.

Both speed conditions (the self-selected speed and a 30% increase in speed) were measured 6 minutes, and the average of the final 2 min of sampling at each walking speed was used for further analysis. We calculated values that were indicated by a respiratory exchange ratio less than 1.0. Absolute value of VO_2 in millilitres per minute (ml/min), relative value of VO_2 in millilitres per kilogram per minute (ml/kg/min), VCO_2 (ml/min), and Metabolism (METs) were averaged over the final two minutes of each trial.

Table 1
Physical characteristics of participating subjects.

Variables	Group (N = 24)		*p*-Value
	Older men (N = 12)	Women (N = 12)	
Age (years)	72.8 ± 4.6	74.7 ± 4.0	0.375
Weight (kg)	69.7 ± 7.9	54.2 ± 7.2	0.000***
Height (cm)	168.3 ± 5.6	152.9 ± 4.3	0.000***
Body mass index (kg/m²)	24.5 ± 2.2	23.2 ± 2.9	0.263

***p < 0.00.

2.4. Statistical analysis

The Shapiro-Wilk test was used to confirm that all outcome variables were normally distributed. Independent *t* test, Mann-Whitney U test and X^2 test were used for comparison of the baseline characteristics of the subjects in both groups (Table 1). Sex differences in gait parameters (cadence, speed, step width, stride length, and step time) and muscle activation (rectus abdominis, external obliques, erector spinae, multifidus, gluteus maximus, gluteus medius, biceps femoris, adductor longus, rectus femoris, vastus medialis, tibialis anterior, and gastrocnemius medialis muscles) were tested for statistical significance using an independent t-test. In metabolic cost analysis, a two-way ANOVA with repeated measures was applied to two groups (older men and older women) and two walking speeds (self-selected speeds and a 30% speed increase). A post-hoc test was performed to determine whether there was any difference in measuring group or walking speed, and a t-test was also applied.

All data were analyzed using SPSS version 21 for Windows (SPSS Inc., Chicago, IL, USA). The average value and standard deviation were calculated for all variables, and the alpha was set at $\alpha = 0.05$.

3. Results

In our comparison of the results between the two groups (older men and women), walking speed was significantly higher in the older men than it was in the women ($p = 0.028$), as was stride length ($p = 0.015$). Older men also had a significantly higher step length on both the right ($p = 0.016$) and left sides ($p = 0.032$) than did the women (Table 2).

In the stance phase, muscle activation of the external oblique ($p = 0.05$) and erector spinae ($p = 0.028$) was significantly higher for the older women than for the men. In the swing phase, muscle activation of the erector spinae ($p = 0.009$) and the multifidus ($p = 0.043$) was significantly higher for the older women than it was for the men (Table 3).

The absolute value of VO_2 (ml/min) of older men was significantly higher at the self-selected speed ($p = 0.011$) and during the 30% increased speed ($p = 0.016$) compared to that of the older women. When the men were only compared with other older men, absolute value of VO_2 (ml/min) was significantly higher for the 30% increased speed ($p = 0.018$) than it was at the self-selected speed. Additionally, relative value of VO_2 (ml/kg/min) of older men was significantly higher for the 30% increased speed ($p = 0.014$) than at the self-selected speed. The absolute value of VCO_2 (ml/min) of older men was significantly higher for the 30% increased speed ($p = 0.048$) than at the self-selected speed. The METs of older men was significantly higher at the 30% increased speed ($p = 0.014$) than at the self-selected speed.

4. Discussion

Walking speed was found to be significantly faster in the older male group than in the older female group. This result is similar to that found in previous studies[18,29] and is widely accepted due to the fact that men generally have a larger body mass than women.[18] However, body mass index was not different between the two groups. Therefore, more physical components between the two older adults should be compared to better understand their differences in walking. Stride length was significantly longer for the older men than for the older women. These results support the observations made in previous studies that stride length was longer for older men than women.[17,19] Step length on the right and left sides was also significantly longer for the older men than for older women. This finding was similar to those reported by other studies.[17,19] Despite the shorter average leg length of women, older men and older women had similar cadence, which did not seem to be influenced by physical size.[17] Therefore, differences in walking speed, body weight, or physical size are not affected, and the influence of other factors must be considered. It has been reported that females protrude their legs less vigorously and include more hip joint adduction during walking than do men.[17] In addition, women have been shown to walk with a higher cadence, shorter step width, greater joint range of motion in the frontal and sagittal planes, increased peak hip adduction angle and moment, and increased internal rotation moment compared to men.[17,19–21] Therefore,

Table 2
Gait parameter.

Parameter	Group		*p*-Value
	Older men	Women	
Cadence (step/min)	108.93 ± 10.68	106.95 ± 13.22	0.690
Speed (cm/min)	104.57 ± 13.69	90.83 ± 14.83	0.028*
Stride length	110.61 ± 14.12	98.02 ± 8.76	0.015*
Step width (cm)	13.88 ± 1.74	12.43 ± 3.26	0.190
Step length of right side (cm)	56.95 ± 7.96	49.37 ± 6.19	0.016*
Step length of left side (cm)	55.52 ± 5.50	50.43 ± 5.37	0.032*
Step time of right side (second)	0.55 ± 0.05	0.56 ± 0.08	0.595
Step time of left side (second)	0.54 ± 0.05	0.56 ± 0.07	0.606

*$p < 0.05$.

Table 3
Muscle activity of trunk and lower-limb for the older men and older women in gait cycle.

Muscles	Stance phase		Swing phase	
	Older men	Older women	Older men	Older women
Rectus abdominis (% mean)	3.19 ± 2.50	3.67 ± 3.43	3.00 ± 2.44	3.57 ± 3.40
External oblique (% mean)	9.33 ± 3.99	12.60 ± 3.74*	9.23 ± 3.96	12.33 ± 4.79
Elector spinae (% mean)	14.42 ± 7.35	24.05 ± 12.08*	13.06 ± 10.73	26.93 ± 13.00**
Multifidus (% mean)	15.15 ± 5.24	19.68 ± 5.68	13.00 ± 6.98	19.23 ± 7.26*
Gluteus maximus (% mean)	12.66 ± 8.90	12.11 ± 5.79	12.09 ± 7.69	9.97 ± 5.69
Gluteus medius (% mean)	17.96 ± 8.37	18.92 ± 9.01	15.44 ± 13.40	13.41 ± 10.18
Biceps femoris (% mean)	20.70 ± 9.23	18.78 ± 11.43	22.95 ± 10.18	21.40 ± 11.21
Adductor longus (% mean)	18.73 ± 7.89	24.56 ± 11.96	17.74 ± 8.02	21.49 ± 8.94
Rectus femoris (% mean)	20.59 ± 7.08	25.04 ± 11.67	18.61 ± 12.77	20.72 ± 14.43
Vastus medialis oblique (% mean)	19.37 ± 11.03	17.45 ± 7.76	15.22 ± 10.19	13.69 ± 11.09
Tibialis anterior (% mean)	11.21 ± 3.94	15.48 ± 8.88	14.97 ± 6.34	15.57 ± 5.49
Gestrocnemiusmedialis (% mean)	19.49 ± 5.46	17.70 ± 7.52	5.98 ± 3.99	5.40 ± 3.22

*$p < 0.05$, older men vs. older women. **$p < 0.01$, older men vs. older women.

when comparing older men and women, differences in walking speed should be considered to affect both physical structure and walking habits. These differences in physical structure related to sex can be seen in young adults, as well as older people. Therefore, sex differences should be considered for improvement of gait and sports rehabilitation strategies in older adults.

Muscle activation of the external oblique and erector spinae was significantly higher in the older female group than the older male group in the stance phase. A previous study[30] found that the normal balance group had a higher degree of muscle activation of the internal oblique before heel contact than did the balance perturbation group in older women. They also explained that it had a positive effect on hip stabilizer muscle activation during the initial stance.[31,32] In the present study, muscle activation of the external oblique was higher for the older women than it was in the older men. This lower activationis considered to be inferior in regard tos afety when walking; older men might require the use of the oblique muscles during walking. Muscle activation of the back muscles (erector spinae) was stronger in the older women than in the men in the stance phase of the gait cycle. A previous study[30] reported that the normal balance group had stronger muscle activation of the multifidus during heel contact than did the balance perturbation group among older women. A different study[33] suggested that the back muscles are responsible for trunk extension and are therefore very important for the rotation of the trunk and pelvis.[34,35] In addition, during the stance phase of the gait cycle, the role of the back muscles is to decelerate the flexion movement. Therefore, activation of the back muscles reflects the stability of the lower limbs during the stance phase of the gait cycle. Older adults might eventually require use of the back muscles in order to maintain safe and efficient walking.

When walking on a treadmill, absolute value of VO_2 (mL/kg/min) was higher in older men than in older women for both speed conditions. This finding is similar to that reported previously.[18,29] Peterson & Martin (2010) suggested that the net cost of walking was significantly higher for older adults than it was for younger adults at all walking speeds, while reported that mass-normalized VO_2 was 8.7% higher in older adults than in young adults, and mass and distance normalized metabolic cost of walking was 18.4% higher in older adults than in younger ones.[11] Therefore, older women have similar treadmill walking pattern as healthy adults and walk more efficiently than older men. In addition, Kang & Chaloupka (2002) reported that relative value of VO_2 (ml/min) was higher in older men compared to older women during walking up all gradients (0%, 5%, 10%, 15%). Thus, older men should aim to increase efficiency with regard to energy metabolism consumption. In the present study, relative value of VO_2 (ml/kg/min), VCO_2 (ml/min), and METs were higher at the 30% increased speed ($p = 0.014$) than at the self-selected speed in older men. There results clearly show a high level of energy consumption during walking in this population.

In summary, these results imply that the trunk muscles appear to be more suitable for older adults than the characteristics of the lower extremity muscles. In addition, it was confirmed that there is a difference in metabolic energy cost and spatio-temporal parameters during gait according to sex in the older adults. Therefore, further studies should focus on the methodological appropriate functional training to improve locomotion characteristics according to the metabolic energy cost in the field of clinical and health care for older adults. This study did have limitation. Data were obtained from a fairly small sample size that was drawn from a defined, relatively community-based older population. Accordingly, the results of this study cannot be generalized to other older population. Further studies should include larger sample sizes.

5. Conclusions

This study showed distinct differences between gait parameters, muscle activation of the lower limbs, and energy metabolism in the walking characteristics of older men and older women. When walking for short periods of time, older women were found to have more efficient muscle activation than older men. In addition, while walking during 6 minutes, older women had a more efficient energy metabolism than their male peers. Finally, sex-related differences must be considered in order to improve gait training strategies in the older adults.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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