LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

ORIGINAL ARTICLE

GAIT ANALYSIS ON INCLINE AND DECLINE SURFACES OF ADULT AND ELDERLY WOMEN WITH DIFFERENT VOLUME OF WEEKLY ACTIVITIES

Ricardo Martins de Souza[1]
André Luiz Félix Rodacki[2]

1. Physical Education, Integrated Colleges of Brazil – UniBrasil – Curitiba, PR.
2. Physical Education, Federal University of Paraná – UFPR – Curitiba, PR.

Mailing address:
Rua Virginia Dalabona, 1.202, casa 65, bairro Orleans. 82310-390.
Curitiba, PR
E-mail: profricardo2006@yahoo.com.br

ABSTRACT

Walking is one of the most natural human movements; however, its efficiency decreases with age progression, mainly during the transposition of incline surfaces, where the risk of accident increases. Objective: To evaluate the differences in gait patterns between active (ACT) and sedentary (SED) elderly compared to adult individuals (ADU) during locomotion on incline surface (ramp). Methods: Forty-five subjects (15 ADU, 15 ACT and 15 SED) walked up and down a ramp with 10% of inclination. The kinematic (Vicon MX-13) and kinetic (Force Plate AMTI) analysis of the gait variables was performed. Results: Reduction on amplitude and impulse power around SED and ACT ankle was identified during the incline gait on the ramp compared with ADU. Major differences between ADU and SED/ACT groups concerning displacement velocity during decline gait were identified, probably due to elastic muscle limitations around the hip. Conclusion: Apparently, the level of physical activity does not influence on the SED and ACT gait; however, an IPAQ limitation in accurately classify this level, may have affected the results. Future longitudinal studies in which individuals are submitted to different physical activity volume are necessary to confirm these findings.

Keywords: ramp, kinematics, physical activity, kinetics.

INTRODUCTION

The incidence of falls increases above 65 years of age and it presents severe consequences in terms of morbidity, mortality and associated costs[1,2]. Some analyses have revealed that approximately 25% of the individuals older than 65 years and 35% of the individuals older than 75 years suffer about one fall per year[3]. In the USA, approximately 10% of the death cases occurred in the work place (6,083 cases), 590 deaths (~10%) were caused by falls, regardless of age. Among these deaths, the great majority (~85%) was reported during crossing of flooring of different levels, such as ramps, steps and stairs[4]. Thus, the crossing of levels requires special attention, mainly to the eldest, who present higher risk of falls when c compared to younger subjects. Additionally, this activity demands requires expressively higher effort than what is observed on the plane surface[5] and constitutes a considerable challenge.

The ramps offer a more accessible option in the crossing of uneven surfaces; however, change in level during locomotion still presents a challenge which is strongly influenced by the physical characteristics of the inclined surface. In Brazil, the ABNT[6] determines that parameters associated with size and maximal inclination of the ramp Nevertheless, the walking behavior of the elderly during crossing of inclined surfaces has still been described in a fairly limited manner.

One of the greatest limitations about the understanding on walking on inclined surfaces is that the majority of the studies analyzed young and healthy individuals[7-11]. In situations of greater challenge, as happens on inclined planes, remarkable alterations in the normal walking pattern of the elderly may occur, especially due to the mechanical and neuromuscular limitations which follow the ageing process[12,13]. Similarly to what occurs on the flat surface, it is expected that a senile locomotion pattern on inclined surfaces is less safe and makes the elderly more prone to falls when compared to younger subjects.

Physical activity has been proposed as an effective way of improving the capacity to perform daily tasks, mobility and locomotion in the elderly[4-16]. Thus, it is expected that the elderly with higher weekly activity volume present differentiated locomotion patterns during locomotion on inclined surfaces compared to those observed in the elderly with low physical activity level. Therefore, the hypotheses that a) the elderly present a pattern which includes alterations in a set of kinematic parameters during the inclined plane compared to the flat plane and that b) physically active elderly present walking patterns which demonstrate lower risk of falls than inactive elderly subjects (sedentary) were tested.

METHODS

Fifteen adults and 30 elderly volunteered to participate in the study. Prior to the beginning of the experiment, all participants were informed about the study's procedures according to the Free and Clarified Consent Form. The experimental procedures of this study were approved by the Ethics in Research Committee of the University of Paraná (UNIPAR), under the protocol 18227/2009, following the resolution 196/96. The participants were sorted in three groups: mature adults (ADU), active elderly (ATI) and sedentary elderly (SED). The elderly were classified according to their volume (in minutes) of physical activities weekly performed, which were determined with the IPAQ questionnaire (version 6, validated to the Brazilian population)[17]. From the IPAQ, the total time (in minutes) dedicated to weekly physical activities was determined. The elderly with higher volume of hours in weekly physical activities were placed in group ATI, while those with lower weekly activities volume were placed in group SED. Table 1 demonstrates the anthropometrical characteristics of the participants and the weekly time spent with physical activities.

Individuals able to perform daily tasks with no external help, with no history of fractures, joint surgeries, low back pain or any other clinical condition which could interfere on the walking pattern in the six months preceding the study were included.

The analysis of the anthropometrical variables did not evidence any difference concerning the mass of the participants ($p \geq 0.05$). However, the elderly presented shorter stature when compared to the adults ($p \leq 0.05$). The total time spent with weekly physical activities was similar between ADU and ATI, and both groups presented weekly activity higher than SED (63.7% and 223.6% higher, respectively). The level of physical activity among the active and sedentary elderly allows us infer that a considerable difference between groups may be obtained.

The gait was analyzed in two experimental conditions which involved locomotion ascending and descending a ramp. The analysis occurred in a single session and the subjects were evaluated barefoot. The evaluation of the gait on ramp occurred on a wooden surface (5.0m long and 1.0m wide) inclined at 10%, which was covered with a rubber rug so that the task could be performed without interference of the shoewear. A 1.0 x 1.0m step was placed at the end of the ramp. The inclination was established within the maximum thresholds recommended by the ABNT (2004) for the designing of access ramps[7].

Each participant performed 10 distances in each experimental condition, in a total of 20 distances; however, only the three first valid cycles were selected for analysis. The dislocation velocity was not controlled and the participants were told to "normally' walk. A cycle was considered valid when the body markers were picked and correctly processed, allowing the complete reconstruction of the movement. Moreover, in order to have an attempt considered valid, the subjects completely stepped on the surface of the forces platform (see description below). Data were normalized in relation to the duration of the walking cycle (successive heel ground contact) and the grouped mean

Table 1. Summary of the anthropometric variables and result of the IPAQ questionnaire.

	ADU	ATI	SED
Mass (kg)	46.61 ± 9.75	64.94 ± 9.10	64.20 ± 8.89
Stature (m)	1.64 ± 0.08	1.58 ± 0.06Ŧ	1.56 ± 0.07▲
Age (years)	25.53 ± 5.82	68.23 ± 5.78Ŧ	65.33 ± 3.33▲
Weekly act (min)	1.308.6 ± 1.030.33	2.587.0 ± 1.114.37	799.33 ± 353.3▲●

(Ŧ) significant difference between ADU and ATI; (▲) significant difference between ADU and SED; (●) significant difference between ATI and SED;ATIV. WEEK– weekly activity volume in minutes measured by the IPAQ; a $p \leq 0.05$ was used.

of three valid cycles was calculated for each participant in each of the experimental conditions.

The kinematic analysis was performed with the aid of an optoelectronic system (Vicon Motus MX-13), composed of six chambers which operated in a 100Hz frequency. Spherical reflexive markers were attached on the following anatomic points of both lower limbs and pelvis: metatarsophalangeal joint of the second finger, lateral malleolus of the tibia, posterior aspect of the calcaneus, on the lateral portion of the mid leg, on the lateral epicondyle of the femur, on the lateral portion of the thigh mid segment, on the anterosuperior iliac spines, sacrum and on the T12 spinal process projection.

Having these anatomic references as a starting point, segments and joints were mathematically created and used in the task's evaluation. The used biomechanical model is similar to the Helen Hayes model[18]. A force platform (AMTI, model OR6-7) was used to obtain the reaction forces of the ground during the gait. The force platform was inserted in the structure on the final part of the lower third of the ramp (approximately at 1.5m of the beginning of the inclined plane). The surface of the forces platform agreed with the ground surface, which made it impossible for the participants to identify its position in any of the experimental conditions. The ground reaction force data were collected at a 1kHz frequency.

A number of kinetic and kinematic variables were analyzed. The kinematic variables comprehended cadence (CAD – number of steps performed per minute), total time of the cycle (TTC – duration of the walking cycle), support time (ST – percentage of the TC in which the assessed limb remains in contact with the ground), oscillation time (OT – percentage of the TTC in which the assessed limb remains in motion), size of the step (SST – distance between the two touching times of the heel of the assessed foot), gait velocity (VEL – velocity of dislocation), velocity of the heel contact (VELH – velocity of the vector resulting from the heel at the moment of touch with the ground), hip range of motion (HROM – difference between the hip flexion and extension movement peak), knee range of motion (KROM – difference between the knee flexion and extension movement peak), ankle range of motion (AROM – difference between the ankle dorsal and plantar flexion movement peak), pelvis rotation amplitude (PELROT – difference between the pelvis left and right rotation movement peak), pelvis anterior inclination (PANTIN – difference between the pelvis anterior and posterior inclination movement peak), pelvis lateral inclination (PLIN – difference between pelvis right and left lateral inclination movement peak). The kinetic variables involved the peaks and the rates of forces application in the beginning of the support phase in the anteroposterior and vertical direction were calculated (FYINI, FZINI and TXFYNI, TXFZINI, respectively). The same parameters were calculated in the end of the cycle (FYFIN, FZFIN and TXFYFIN and TXFZFIN, respectively).

The Kolmogorov-Smirnov test was applied and corroborated the data normality. A set of multifactorial ANOVA analyses of variance with repeated measures was applied to test the differences between groups (ADU, ATI and SED). The Tukey test was applied to identify where the differences occurred. The statistical tests had significance level of $p \leq 0.05$ and were performed through specific software (Statistica, StatSoft USA, version 7.0).

RESULTS

During the experimental procedures, the participants were able to comfortably walk in all conditions (incline and decline). None of the participants reported any kind of discomfort during the task performance and all of them satisfactorily completed the proposed protocol.

Table 2 summarizes the results found in the kinematic variables concerning the spatial-temporal organization of the gait cycle among ADU, ATI and SED in the incline and decline ramp conditions.

The TXFYINI of ADU (519.5 ± 191.5N.s^{-1}) was lower ($p \leq 0.05$) than of SED (1,399.5 ± 1,956.6N.s^{-1}), but did not differ from ATI ($p > 0.05$; 614.6 ± 553.9N.s^{-1}). The TXFYFIN of ADU (1,230.8 ± 761.8N.s^{-1}) was higher ($p \leq 0.05$) than of SED (609.2 ± 394.3N.s^{-1}), but was not different from ATI ($p > 0.05$; 888.5 ± 510.3N.s^{-1}). The other kinetic variables did not present differences between conditions ($p \geq 0.05$) and groups ($p \geq 0.05$). The summary of the other variables for INC and DEC is presented in table 3.

Table 2. Result of the kinematic variables concerning the spatial-temporal organization of the walking cycle in the ramp incline and decline conditions.

	INCLINE		
	ADU	ATI	SED
SST (m)	1.41 ± 0.08	1.20 ± 0.08Ŧ	1.17 ± 0.09▲
VEL (m.s-1)	1.30 ± 0.10	1.11 ± 0.15	1.08 ± 0.14
VELH (m.s-1)	1.19 ± 0.47	1.05 ± 0.38	1.04 ± 0.49
TTC (s)	1.09 ± 0.06	1.10 ± 0.14	1.09 ± 0.08
CAD (steps/s)	55.20 ± 3.14	55.54 ± 6.85	55.31 ± 4.85
ST (%)	63.23 ± 1.46	64.37 ± 2.18	64.73 ± 2.04
OT (%)	33.77 ± 1.46	35.63 ± 2.18	35.27 ± 2.04
	DECLINE		
	ADU	ATI	SED
SST (m)	1.38 ± 0.10	1.08 ± 0.15Ŧ	1.06 ± 0.10▲
VEL (m.s-1)	1.39 ± 0.13	1.08 ± 0.19Ŧ	1.05 ± 0.12▲
VELC (m.s-1)	1.43 ± 0.45	0.94 ± 0.33	0.80 ± 0.27▲
TTC (s)	1.00 ± 0.05	1.01 ± 0.09	1.01 ± 0.06
CAD (steps/s)	60.26 ± 2.90	59.83 ± 5.12	59.73 ± 3.87
ST (%)	62.33 ± 2.89	64.70 ± 4.23	65.13 ± 4.95
OT (%)	37.67 ± 2.89	35.30 ± 4.23	34.87 ± 4.95

(Ŧ) statistically significant difference between ADU and ATI; (▲) significant difference between ADU and SED; (●) significant difference between ATI and SED. $p \leq 0.05$ was used.

Table 3. Result of the kinematic and kinetic variables assessed in the ramp ascend and descend conditions.

	INCLINE		
	ADU	ATI	SED
HROM (º)	55.9 ± 5.4	55.7 ± 5.5	53.3 ± 7.7
KROM (º)	55.9 ± 3.8	53.9 ± 5.8	51.3 ± 9.0
AROM (º)	43.2 ± 7.4	29.1 ± 3.2Ŧ	31.2 ± 8.2▲
PLROT (º)	14.1 ± 9.6	9.6 ± 3.0	7.2 ± 2.7
PLINC (º)	16.6 ± 5.9	10.8 ± 1.9	8.6 ± 3.4▲
PANTINC (º)	4.2 ± 1.0	3.2 ± 1.2	3.2 ± 1.3
FYINI (N)†	49.5 ± 18.5	51.0 ± 12.2	49.4 ± 19.6
FYFIN (N)††	-175.7 ± 33.7	-163.0 ± 26.9	-144.6 ± 41.6
TXFYINI (N.s^{-1})†	519.5 ± 191.5	614.6 ± 553.9Ŧ	1.399.5 ± 1.956.6
TXFYFIN (N.s^{-1})	-1.230.8 ± 761.8	-888.5 ± 510.3Ŧ	-609.2 ± 394.3
FZINI (N)	583.8 ± 107.9	660.0 ± 82.5	618.8 ± 129.4
FZFIN (N)	657.3 ± 91.4	706.7 ± 91.6	634.4 ± 121.3
TXFZINI (N.s^{-1})	3.609.5 ± 991.9	3.718.1 ± 569.2	3.367.7 ± 1.086.4
	DECLINE		
	ADU	ATI	SED
HROM (º)	39.9 ± 5.6	37.5 ± 8.5	37.1 ± 5.1
KROM (º)	61.3 ± 5.0	63.2 ± 8.1	58.6 ± 4.6
AROM (º)	28.0 ± 8.5	26.4 ± 7.0	25.1 ± 5.7
PLVROT (º)	18.0 ± 3.4	15.5 ± 6.7	8.8 ± 5.5
PLIN (º)	14.0 ± 4.5	8.1 ± 2.4Ŧ	7.4 ± 2.0▲
PANTINC (º)	4.2 ± 1.3	4.0 ± 1.4	3.5 ± 1.2
FYINI (N)	102.20 ± 20.2	69.4 ± 30.7	81.2 ± 20.7
FYFIN (N)	-170.0 ± 36.1	-149.1 ± 36.7	-129.1 ± 31.7
TXFYINI (N.s^{-1})	190.0 ± 38.8	129.3 ± 57.5	148.4 ± 40.2
TXFYFIN (N.s^{-1})	-389.6 ± 78.7	-341.5 ± 9.8	-297.3 ± 71.1
FZINI (N)	683.3 ± 110.0	700.2 ± 88.7	671.6 ± 116.2
FZFIN (N)	537.0 ± 102.5	611.7 ± 89.6	599.2 ± 93.3
TXFZINI (N.s^{-1})	4.846.6 ± 1.206.0	4.460.8 ± 912.1	3.931.2 ± 830.0

(Ŧ) difference between ADU and ATI at the same condition (ASC or DES); (▲) statistically significant difference between ADU and SED at the same condition (ASC or DES); (●) statistically significant difference between ATI and SED at the same condition (ASCB or DES); for all comparisons $p \leq 0.05$ was used; forces and rates with positive values indicate that FRS occurred in the posteroanterior direction, and negative values indicate that FRS occurred in the anteroposterior direction.

DISCUSSION

The present study aimed to verify the differences in the behavior between gait of younger and older subjects during the crossing of incline and decline surfaces. Additionally, the influence of the volume of weekly physical activity in the crossing of incline and decline surfaces was assessed. The hypothesis that older individuals would present differences of kinematic and kinetic variables behavior compared to younger subjects was tested. Furthermore, the hypothesis that the elderly with higher level of weekly physical activity would present walking pattern more similar to the younger subjects than to the elderly with lower weekly activity was also tested.

The quantity of investigations which tested experimental conditions similar to the present study is low. Thus, a group with a sample of adults was included in this study so that the results could be compared with the groups of elderly (ATI and SED).

Great part of the necessary energy to go up the ramp is acquired from the fast and powerful extension of the ankle at the end of the support phase[19]. In the present study, reduction in the amplitude around the ankle was identified in the ATI and SED groups compared to the ADU. Besides this decrease in amplitude, decrease in the TXFYINI was observed during the ascend move, which indicated loss of capacity to generate fast force transfer in the anteroposterior direction. Kemoun *et al.*[19] found similar results in older individuals with falls when compared to subjects from the same age group who did not suffer fall. Individuals with higher predisposition to falls presented reduction of forces around the ankle and reduction of range of motion of this articulation. This fact indicates that the elderly are more prone to falls in comparison to adults, and that the level of weekly physical activity was not able to decrease the risks during the crossing of planes.

Reduction in the articular amplitude during dynamic tasks is caused by alterations in the muscular tissue, which involve: a) loss of elastic capacity, which limits the flexion and extension peak of all articulations; and b) decrease of contractile capacity, which decreases the power generated in the transition of the support phase to the oscillation phase, and that consequently determines the size of the step[13]. This reduction may also be associated to the need of the elderly to perform the task more carefully and safely, applying a specific motor control strategy[20].

Christiansen[21] was able to modify parameters of the walking motor pattern, such as the velocity of dislocation, with a program of stretching exercises of the extensor muscles of ankle and flexor muscles of the hip, showing real limitation caused by this musculature in older individuals. The biarticular muscles around these articulations have as one of their functions to use their elastic capacity to accumulate and transfer energy and control the movement in the adjacent articulation[22]. This capacity is partially reduced in the older individual by the alterations in the tissues which reduce their elasticity. Previous studies showed that the adoption of stretching[23-25] and strength exercises programs[14] positively contribute to the decrease of falls while walking.

Decrease in ankle articular amplitude can also have influenced on the application of forces on the ground, especially on SED. Such reduction was observed on the rate of application of the Fy on the anteroposterior direction, which ended up interfering on the capacity to push the ground, causing a smaller step.

During the decline movement, the alterations found were different from those identified during the ramp incline movement. The elderly presented differences compared to the adults, especially in the variables which determine or influence on the velocity of dislocation.

In the present experiment, reduction of velocity during the decline may have been influenced by a series of factors. Part of the reduction in velocity may have occurred due to the lower stretching capacity of the hip flexor musculature, which determines the step amplitude. Reduction in articular amplitude, which is generally found in the elderly, may have reduced pelvic movement, which determined reduction of pelvic amplitude of lateral inclination (LIPV). This lateral inclination has been described as determinant of the size of the step[26].

Besides the reduced capacity to generate torque around the articulations, the descend from the ramp demands eccentric contractions, which end up being more difficult to control by a fragile musculature such as in sedentary elderly subjects. It was expected that the demand involved in the ramp ascend and descend would cause greater adjustment in the sedentary elderly who present lower capacity to generate torque. However, the elderly presented differences compared to the group of adults, indicating that other factors which follow aging influence more on the crossing of the plane than the level of physical activity.

Increase of the surface inclination to the descend increases the magnitude of the ground reaction forces, especially in the anteroposterior direction[6]. The increase rate of this force is straightly connected with the velocity of the heel contact with the ground, which ends up increasing the rate of transference of forces between the foot and the plane. In case the surface does not offer the necessary friction during the heel contact, the probability of the foot sliding and onset of slip and fall increases. In the present study, especially in elderly with lower physical activity, the velocity of contact of the foot with the ground increased, which may indicate increase in the risk of accidents during this task.

The found results let us conclude that the walking pattern of the individuals is directly influenced by the surface where locomotion occurs. ATI and SED elderly individuals suffer alterations in the motor pattern of the task significantly different from the ADU subjects, indicating hence greater difficulty in the maintenance of a pattern considered less prone to falls.

Apparently, significant differences have not been identified in the walking motor pattern which could have been influenced by the different volume of weekly physical activity. However, this could have been a result from the incapacity the used questionnaire presented in identifying different types and intensities of the activities performed, which can directly influence on the physical capacity of the individuals.

Further longitudinal studies which could compare the influence of systematized and controlled programs of physical activities on the walking motor patterns become necessary.

REFERENCES

1. Honeycutt PH, Ramsey P. Factor contributing to falls in elderly men living in the community. Geriatr Nurs 2002;23:5.
2. Scarborough DM, Krebs DE, Harris BA. Quadriceps muscle strenght and dynamic stability in elderly persons. Gait Posture 1999;10:10-20.
3. Van Dieën JH, Pijnapples M, Bobbert MF. Age-related intrinsic limitations in preventing a trip and regaining balance after a trip. Safety Science 2005;43:437-53.
4. Toscano G, Windau J. Fatal work injuries: results from the 1992 national census. Month Larb Rev 1993;39-48.
5. Hunter LC, Hendrix EC, Dean JC. The cost of walking down hill: is the preferred gait energetically optimal? J Biomech 2010;43:1910-5.
6. ABNT. Norma brasileira NBR9050: acessibilidade à edificações, mobiliário, espaços e equipamentos urbanos. Rio de Janeiro: ABNT, 2004
7. Redfern MS, Dipasquale J. Biomechanics of descending ramps. Gait Posture 1997;6:119-25.
8. Cham R, Redefern, MS. Change in gait when anticipating slippery floors. Gait Posture 2002a;15:159-71.
9. Mcintosh AS, Beatty KT, Dwan LN, Vickers DR. Gait dynamics on inclined walkway. J Biomech 2006;39:2491-502.
10. Cham R, Redefern MS. Heel contact dynamics during slip events on level and inclined surfaces. Safety Science 2002b;40:559-76.
11. Leroux A, Fung J, Barbeau H. Postural adaptation to walking on inclined surface: I. Normal strategies. Gait Posture 2002;15:64-74.
12. Gajdosik RL, Linden DWV, Williams AK. Influence on age and length and passive elastic stiffness characteristics of the calf muscle-tendon units of women. Phys Ther1999;79:827-38.
13. Prince F, Corriveau H, Hébert R, Winter DA. Gait in elderly. Gait Posture 1997;5:128-35.
14. Lamoureux E, Sparrow WA, Murphy A, Newton RU. The effect of improved strength on obstacle negotiation in community-living older adults. Gait Posture 2003;17:273-83.
15. Wolf SL, Barnhart HX, Kutner NG, McNeely E, Coogler C, Xu T, Atlanta FICSIT Group. Reducing frailty and falls in older persons: an investigation of tai chi computerized balance training. J Am Geriatr Soci 2003;51:1794-803.
16. Lan C, Lai JS, Chen SY, Wong MK. Tai chi chuan to improve muscular strength and endurance in elderly individuals: a pilot study. Arch Phys Med Rehabil2000;81:604-7.
17. Pardini R, Matsudo SM, Araújo T, Matsudo V, Andrade E, Braggion G, et al. Validação do questionário internacional de nível de atividade física (IPAQ - versão 6): estudo piloto em adultos jovens brasileiros. Rev Bras Cie Mov2001;9:45-51.
18. Kabada MP, Ramakrishnan ME, Wooteten J, Gainey J, Gorton G, Cochran GVB. Repeatability of kinematic, kinetic and electromyographic data in normal adult walk. Journal of Orthopaedic Research 1989;7:849-60.
19. Kemoun G, Thomie P, Boisson D, Guieu J. Ankle dorsiflexion delay can predict falls in the elderly. J Rehabil Med 2002;34:278-83.
20. Noble JW, Ritsma BR, Frank JS, Prentice SD. Locomotor strategies for walking up inclined surfaces in older adults. Abstract from the 14th Conference of the Canadian Society for Biomechanics 2006. Waterloo, ON, Canada.
21. Christiansen CL. The effects of hip and ankle stretching on gait function of older people. Arch Phys Med Rehabil 2008;89:1421-8.
22. Whittington B, Silder A, Heiderscheit B, Thelen DG. The contribution of passive-elastic mechanism to lower extremity joint kinetics during human walking. Gait Posture 2008;27:628-34.
23. Cristopoliski F, Barela JA, Leite N, Fowler NE, Rodacki ALF. Stretching exercise program improves gait in the elderly. Gerontology 2009;55:614-20.
24. Kerrigan DC, Lee LW, Collins JJ, Riley PO, Lipsitz LA. Reduce hip extension during walking: healthy elderly and fallers versus young adults. ArchPhys MedRehabil2001;82:26-30.
25. Kerrigan DC, Xenopoulos-Odsson A, Sullivan MJ, Lelas JJ, Riley PO. Effect of a hip flexor-stretching program on gait in the elderly. Arch Phys Med Rehabil2003;84:1-6.
26. Rose J, Gamble JG. Human walking. 2 ed. Baltimore: Williams & Wilkins, 1994.