The Effect of Plantar Foot Pressure Negotitating Obstacles in the Elderly

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Purpose: This research investigated falls due to obstacles that occur among elderly people by assessing changes in the values of plantar foot force, peak force, and plantar foot pressure in elderly subjects while they were stepping over obstacles of different heights.

Methods: The subjects were 20 elderly people aged 70-80 years; Pressure was measured on flat ground(0 cm), and after installing obstacles of 8 cm and 12 cm using the F-scan system, which is a resistance-type pressure sensor. A one-way analysis of variance was performed to compare pressure on each part of the foot according to various heights after collecting data using the Tekscan program. The least significant difference test was used for the post-hoc analysis, A p-value <0.05 was considered significant.

Results: The force value for the toe area (parts 1, and 2) and contact pressure increased significantly with the 12 cm obstacle ($p<0.05$). The peak force value and the peak contact pressure for part 1 increased significantly with the 12 cm obstacle ($p<0.05$).

Conclusion: Larger changes appeared in the functions and structure of the foot while subjects walked over obstacles of different heights compared to flatland walking. This result suggests that people have safety strategies to prevent falls, and that there is a need for a more realistic approach through practice to overcome obstacles of various heights to prevent falls.

Keywords: Falls, Height of obstacle, Plantar region, Contact pressure

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I. Introduction

Thirty-five regions in Korea are classified as the “super-aged society”, in which more than 20% of the total population is senior citizens > 65 years of age.[1] Senior citizens are not only experiencing social issues, but frequently suffer from injuries and wounds during the aging process.[2] The rate of death caused by falling increases as aging progresses,[3] and, in particular, injuries due to obstacles occur most frequently.

Human aging brings physical changes, such as, a decline in the sense of equilibrium, atrophy in nervous system functions, decrease in walking ability, and weakening of muscles.[4] Loss of muscle and joint mobility leads to a loss of functional independence,[5] and time delays due to a decline in the number brain cells, reduced production of neurotransmitters, and declined in hearing and a sense of equilibrium. Functional declines in visual and somatosensory systems cause declines in cognitive ability and loss of balancing ability, inducing changes in walking ability due to increased postural swing.[6] These changes increase the risk for falling, and fall in the elderly often develop into a serious condition leading to death. Most of the reasons for falling can be predicted in advance. [7-11]

Efforts to understand the mechanisms of movement are actively in progress in the motor mechanics field for the purpose of preventing falls in the elderly. Petraca, et al.[12] by setting the heights of obstacles proportional to the length of the lower limbs of subjects, Chen, et al.[13] set heights of 2, 5.2, and 15.2 cm, which are typical heights of the floor, thresholds of rooms and bathrooms, street curbs, and toys, Han et al.[14] set the height of obstacles to 10, 20, and 30 cm. Additionally, Austin, et al.[15] tested 4 different heights of 31 mm and 125 mm, which are threshold heights and the general height of the curb, respectively, and 76 mm and 0 mm, which represented the flatland. As a result, significant changes in joint movement were observed according to the different heights and increased the risk for falling. Similar and more realistic studies are being conducted by testing various heights to fit different situations in which falls occur.[16]

The analysis of plantar foot pressure is an actively researched field in clinical and research sports science. Plantar foot pressure analysises are useful to quantify static and dynamic pressure on the feet during walking. This type of analysis determines the pressure that is applied to specific parts of the foot during movements,[17] and it is helpful for the diagnosis and treatments of injuries by measuring and analyzing pressure distribution. Additionally, patient's foot problems can be understood by analyzing foot pressure in connection with a stance phase analysis of walking and it can be an indicator of treatment progress.[18]

Results of recent walking studies using different heights of various obstacles are meaningful for analyzing bioepidemiological characteristics, but it is still difficult to understand physical mechanisms that can cause falls in the elderly based only on the heights and detailed changes in foot pressure with a limited kinematics analysis. Therefore, we subdivided the plantar foot force value into a peak force value, a plantar foot pressure value, and the peak plantar foot pressure value in seven detailed areas to observe and suggest falling prevention training to overcome obstacles.

Ⅱ. Methods

1. Subjects

This study was conducted from May 1 to May 20, 2011 with 20 senior citizens between the ages of 70～80 years from the D College for Senior Citizens in Gyeongbuk. All subjects had good cognitive function could walk independently, had no foot lesions to affect walking, had not undergone surgery within 1 yea, and had completed the experimental agreement form after the experimental procedures were explained to them in detail.

Of the 20 subjects, 10 were men and 10 were women. The average age was 72.1±0.5 years old, height was 160.5±1.2 cm, and weight was 61.2±1.7 kg (Table 1).

Table 1. Common characteristics of subject

	Experimental group (n=20)
Gender (male/female)	10 / 10
Age (year)	72.1±0.5
Height (cm)	160.5±1.2
Weight (kg)	61.2±1.7
Foot Length (R/L)	247.5/247.5

Values are Mean±SD

2. Experimental Method

This research was performed over 20 days in a classroom at the College for Senior Citizens; the room temperature was kept at 20℃.

1) Obstacle preparation

A rectangular wooden board (2 cm wide, 1 cm high, and 1m long) was prepared, wooden rod obstacles painted in red were attached, and 8 and 12 cm were marked on the board. An obstacle height of 8 cm was set as a similar height to a room threshold or bathroom threshold, and 12 cm was set as a similar height for a sidewalk. The obstacles were situated to fall off even with a slight touch, considering the safety of elderly subjects.[19]

2) Measurement Method

(1) Experimental procedure

Each subject was measured for the 0, 8, and 12 cm obstacles. First subjects were seated in a chair for 10 minutes to stabilize. Thereafter, an insole type measuring tool was installed, and the subject was instructed to walk at a comfortable walking speed (80 m/s) on a treadmill for 5 minutes. The experiment was conducted with a random order of obstacle heights. Before the subjects walked over the obstacles, they were told to step on the foot mat with the right foot. Each experimental task was performed three times, and the highest value was taken.

(2) Experimental equipment

An F-scan system (Tekscan Inc., Boston, MA, USA), which is an insole-type resistance ressure sensor, was used to measure the pressure applied to the sole of the foot during the stance phase when the subject was stepping over the obstacles. The width of the pressure sensor was 702.6 mm and it was composed of 44 horizontal and 52 vertical sensors. The slippers were prepared according to the shos sizes of the subjects and were 230～280 mm in 5 mm increments.

The pressure distribution data while walking was collected at a speed of 60 frames/sec. Each area was analyzed with the Tekscan program after classifying the areas of the feet using the Tekscan Pressure Measurement System version 5.23.

(3) Plantar area division

Rather than obtaining one composite value related to the plantar foot pressure, feet were divided into seven areas, including the hallux, lesser toes, first metatarsal phalangeal joint (MPJ), second-third MPJ, fourth-fifth MPJ, midfoot, and heel to analyze the characteristics of the pressure distribution of each area by segmentalization.[20]

3. Data Analysis

Data were analyzed using SPSS Windows 12.0 program (SPSS, Inc., Chicago, IL, USA). The average and standard deviation for the measured plantar foot pressure values of each subjects were calculated during walking with obstacles, and a one way analysis of variance was performed to compare the differences among the seven areas of the foot, peak force, contact pressure, and peak contact pressure. A post hoc analysis was conducted using the least significant difference test. A p-value < 0.05 was considered significant.

III. Results

1. Force value

The force value in the toe area (areas 1, and 2) increased significantly while walking with an obstacle height of 12 cm compared to that of flatland walking and walking with an obstacle height of 8cm ($p<0.05$). The force value for the front part of the foot (areas 3, 4, and 5), midfoot area (area 6), and heel area (area 7) increased slightly but not significantly ($p>0.05$)(Table 2).

A statistically significant increase occurred only in area 1 with obstacle heights between 8 and 12cm ($p<0.05$)(Table 2)(Figure 1).

2. Peak force value

The toe area force (area 1) increased significantly while walking on flatland and with obstacle heights of 8 and 12 cm ($p < 0.05$). The force value of the toe area (area 2), front foot area (areas 3, 4, and 5) and metatarsal area (area 6) tended to increase as the height of the obstacles increased ($p > 0.05$). The force value tended to decrease in the heel area (area 7) with an obstacle height of 8 cm and tended to increase with an obstacle height of 12cm ($p>0.05$)(Table 3).

A statistically significant increase occurred only in area 1 with obstacle heights between 8 and 12 cm ($p<0.05$)(Table 3)(Figure 2).

3. Contact pressure

Compared to flatland walking, contact pressure tended to increase in the toe area (areas 1 and 2) as obstacle height

Table 2. The segment force value measurement while the three obstacles height change (N)

Foot region	Obstacle 0 cm	Obstacle 8 cm	Obstacle 12 cm	F	p
Region 1	13.75±1.88	13.80±1.81	20.70±4.81	1.86	0.04*
Region 2	10.44±1.50	10.97±1.71	11.51±1.40	0.12	0.05
Region 3	28.37±2.86	28.30±1.84	28.58±2.55	0.00	0.39
Region 4	7.04±1.62	7.01±1.18	7.09±1.02	0.00	0.19
Region 5	37.79±1.78	34.52±3.66	42.33±2.72	1.92	0.16
Region 6	7.80±0.88	8.69±1.04	9.36±1.72	0.36	0.70
Region 7	9.79±1.25	9.06±0.75	11.57±1.06	1.52	0.21

* $p<0.05$
Values are Mean±SD
Region 1: Hallux, Region 2: Lesser toe, Region 3: 1st metatarsal head, Region 4: 2nd metatarsal head, Region 5: 3rd-5th metatarsal head, Region 6: Midfoot, Region 7: Heel

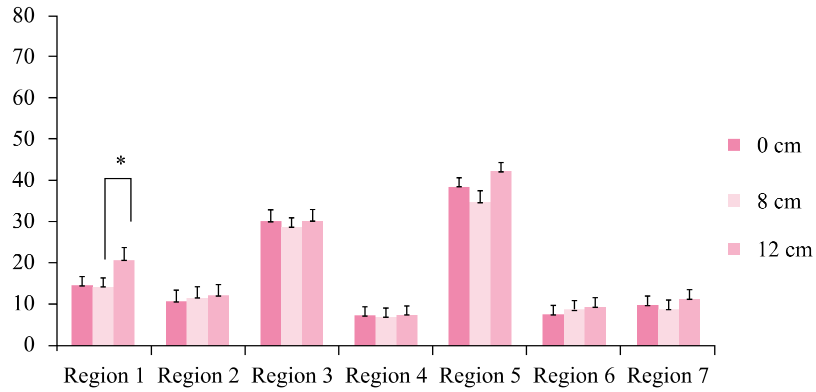

Figure 1. Comparison of force value changes for each area according to the height of obstacles. (N)
* p<0.05

Table 3. The segment peak force value measurement while the three obstacles height change (N)

Foot region	Obstacle 0 cm	Obstacle 8 cm	Obstacle 12 cm	F	p
Region 1	2.47±0.27	2.65±0.32	3.57±0.43	2.83	0.02*
Region 2	2.05±0.26	2.08±0.19	2.15±0.37	0.35	0.52
Region 3	3.80±0.43	3.86±0.32	4.09±0.51	0.13	0.89
Region 4	0.96±0.16	1.11±0.16	1.36±0.28	0.89	0.42
Region 5	2.86±0.23	2.86±0.35	3.25±0.29	0.45	0.64
Region 6	1.98±0.23	2.15±0.28	2.19±0.34	0.14	0.87
Region 7	3.16±0.39	3.16±0.32	3.69±0.35	0.82	0.45

* p<0.05
Values are Mean±SD

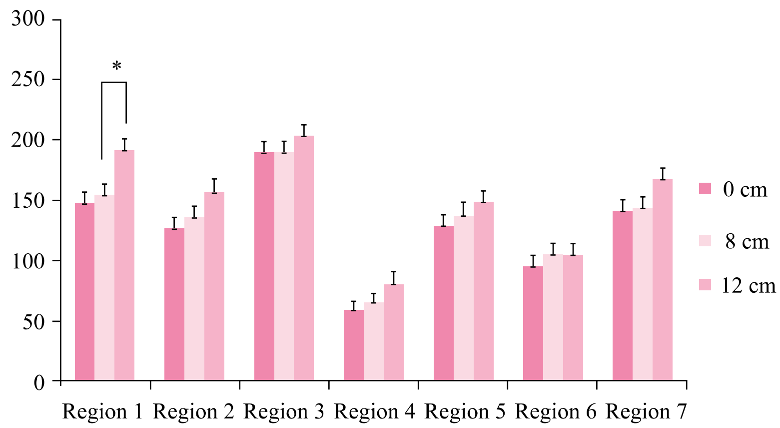

Figure 2. Comparison of peak force value changes for each area according to the height of obstacles. (N)
* p<0.05

increased (p > 0.05). Front foot area contact pressure (area 3, 4, and 5), the metatarsal area (area 6), and the heel area (area 7) also tended to increase as obstacle height increased (p>0.05)(Table 4).

A statistically significant increase occurred in both areas 1 and area 2 in between flatland walking and an obstacle height of 8cm, and with obstacle heights between 8 and 12cm (p<0.05) (Table 4) (Figure 3).

4. Peak contact pressure

Compared to flatland walking, peak contact pressure for each

Table 4. The segment contact pressure value measurement while the three obstacles height change (KPa)

Foot region	Obstacle 0 cm	Obstacle 8 cm	Obstacle 12 cm	F	p
Region 1	147.85±14.62	154.50±18.80	193.40±17.03	2.12	0.01*
Region 2	127.70±15.85	135.40±15.85	156.55±29.26	0.50	0.01*
Region 3	190.10±17.87	190.15±14.00	205.30±20.46	0.25	0.08
Region 4	58.75±8.32	64.85±7.58	80.15±13.23	1.21	0.31
Region 5	129.30±8.78	137.45±17.31	148.05±11.25	0.54	0.59
Region 6	96.20±8.78	105.50±10.87	105.60±12.88	0.24	0.77
Region 7	141.70±12.46	144.40±11.23	167.10±13.02	1.29	0.28

* $p<0.05$
Values are Mean±SD

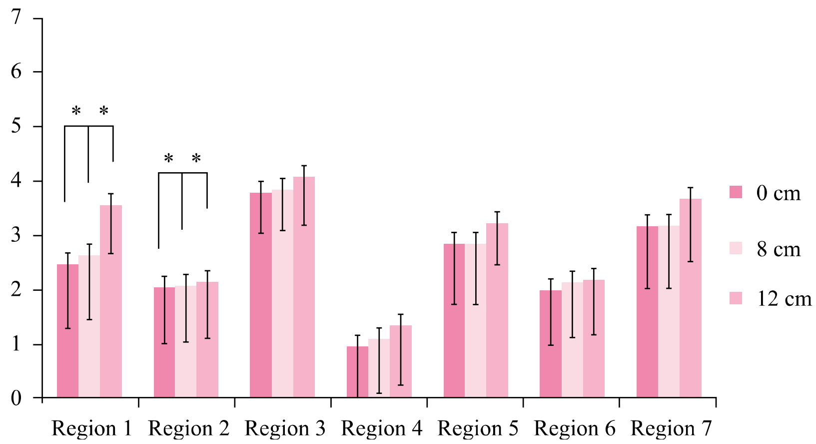

Figure 3. Comparison of contact pressure value changes for each area according to the height of obstacles. (KPa)

* $p<0.05$

area showed significant increases as obstacle height increased in the toe area (area 1)($p<0.05$). Peak contact pressure in the toe are (area 2), front feet area (areas 3, 4, and 5), metatarsal area (area 6), and heel area (area 7) tended to increase as obstacle height increased ($p>0.05$)(Table 5).

A statistically significant increase occurred only in area 1 between flatland walking and an obstacle height of 8 cm ($p<0.05$)(Table 5)(Figure 4).

Table 5. The segment peak contract pressure value measurement while the three obstacles height change (KPa)

Foot region	Obstacle 0 cm	Obstacle 8 cm	Obstacle 12 cm	F	p
Region 1	238.60±26.43†	255.60±31.24	343.50±41.99	2.77	0.04*
Region 2	201.70±18.63	213.75±25.87	245.20±39.49	0.59	0.06
Region 3	364.50±30.50	370.35±41.39	393.30±49.13	0.14	0.87
Region 4	97.15±16.01	116.25±16.90	140.00±26.30	1.12	0.33
Region 5	276.00±34.59	284.95±22.80	312.55±28.37	0.43	0.65
Region 6	195.50±21.39	211.05±26.37	216.30±32.14	0.16	0.85
Region 7	237.45±26.76	300.70±25.84	331.80±40.88	2.27	0.11

* $p<0.05$
Values are Mean±SD

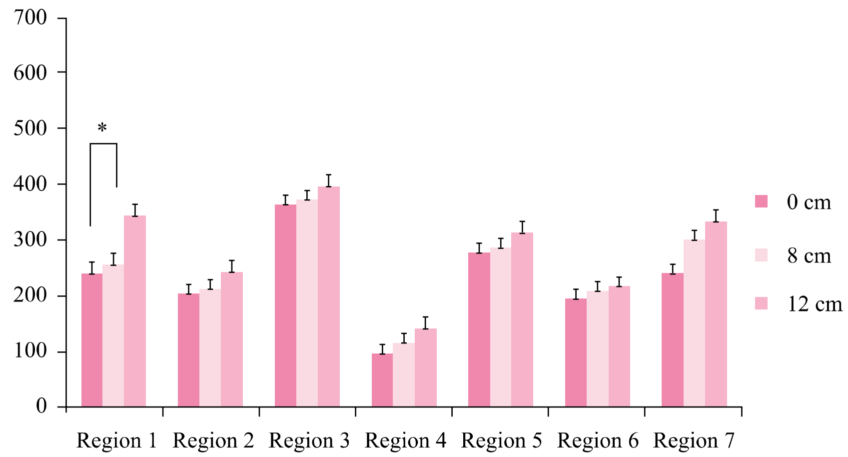

Figure 4. Comparison of peak contact pressure value changes for each area according to the height of obstacles. (KPa)

* p<0.05

IV. Discussion

Aging is accompanied by the weakening of muscles, muscle weight loss, and a decline in walking ability due to limited joint movement and physiological capabilities. Because of the decline in flexibility and resilience, coping skills for unexpected situations decrease leading to an increased risk of falling and a decreased capability of maintaining an independent life style.[21] In particular, the rapid loss of muscle strength in elderly people over 60 years decreases their ability to maintain walking speed and posture and can cause difficulties conducting daily activities in severe cases. Ultimatedly, it increases the risk of injuries in senior citizens.[22,23] General walking is a basic form of movement, and the most important factor for elderly people while walking around obstacles is to step over an obstacles safely. If the a foot is caught on an obstacle, the center of weight moves towards the front of the body increasing the risk for falling.

Previous studies have reported that the minimum perpendicular distance between an obstacle and the first foot that steps over the obstacle is an indicator of safe walking with obstacles.[24]

The plantar foot pressure measurement represents 60% of the walking cycle, including the stance phase on one side and the stance phase of both feet. During the stance phase, the ankle joint sole flexor controls rotation of the tibia and helps push the weight forward on one side during the stance phase.[25,26] The hip adductor joint plays a key role in movement control on the frontal plane during the mid phase of the stance.[27] Kernozek, et al.[28] reported that they observed the plantar foot pressure applied to specific parts of the foot during functional activities and various daily life movements, and could readily analyze the balance impairment that can occur during walking or standing still. This type of study also provides useful and objective information for treatments of various diseases related to not only the foot area, but also the ankle joint.[29]

In this study, a tendency for the force and peak of each area to increase as the height of obstacles rose was observed, and the force value for the toe (areas 1 and 2) and the heel areas showed a relatively greater increase as the height of the obstacles increased. The reason that the heel area had the highest force is that elderly subjects move the center of weight to the posterolateral side of the supporting foot to lift the lower limb up higher to acquire stability while walking and going over an obstacle.

Sparrow, et al.[24] studied the characteristics of 12 normal adults walking while stepping over obstacles of different heights. As a result, lifting the foot in the foregoing limb was not affected as the subjects were crossing different obstacles which were 10%, 25%, and 40% of their leg length, as the height of the obstacles increased. This is a strategy to provide spatio-temporal composure for the heel part of the foot to safely step over obstacles by reducing burden as they step over tall obstacles.

Yuh, Minwoo, et al.[30] reported that peak force tended to increase as speed increased, and a large difference was observed for the changes in the peak force for each area of the foot, particularly for the toe area according to the speed of walking. We also found that the force value in the toe area increased along with obstacle height.

When the contact pressure and the peak contact pressure were compared as the height of obstacles increased, an increasing tendency was shown, and the toe and heel contact pressure (areas 1 and 2) showed a relatively higher increase in pressure as the height of the obstacles increased. Thus, the peak pressure value in the toe area (areas 1 and 2) that increases as the height of the obstacles increase is a phenomenon that occurs as toes push the ground harder to gain the pushing force to step over the obstacle. This is similar to a study by Park, et al.[31] and Stewart; in which the changes in peak pressure increased only in the front foot as the height of the obstacles was increased. Said, et al.[33] performed an experiment with 12 hemiplegia patients and 12 healthy adults stepping over a 4 cm obstacle, and focusing on the following lover limb to find an appropriate location for the obstacle was a safety strategy.

The results of this study indicated that an increase in sole peak pressure and peak force occurred mostly in the toe area, front foot area, and heel area while stepping over obstacles compared to walking on flatland. This result was similar to that of a study by Han et al. [14] who showed a relatively higher increase in peak pressure only in the front foot as the height of obstacles increased, while normal adults stepped over obstacles of different heights.

Plantar foot pressure of 20 senior citizens was analyzed in relation to the heights of obstacles. The results showed that the pressure increased in the front and rear plantar areas as the height of obstacles increased. Continuous efforts should be made to conduct fall preventive training for the safety of senior citizens. More studies about the effects of step heights and slope angles of on plantar foot pressure while walking on stairs or a ramp must be conducted.

Author Contributions

Research design: Seo KC
Acquisition of data: Kim HA
Analysis and interpretation of data: Kim HT
Drafting of the manuscript: Seo KC, Kim HA, Kim SK
Administrative, technical, and material support: Kim JS
Research supervision: Kim JS

References

1. Statistics Korea. Statistic collection, Statistics Korea, 2006.
2. Campbell AJ, Borrie MJ, Spears GF et al. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing. 1990;19(2):345-6.
3. Choi DW. The Characteristics of Patiences Experiencing Falls in Regard to their Physical Functional Abilities, Medical History at the Health Promotion Medicine Center. Journal of Sports and Leisure Studies. 2009;35(2):783-70.
4. Blake AJ, Morgan K, Bendall MJ et al. Falls by elderly people at home: prevalence and associated factors. Age Ageing. 1988;17(6):365-72.
5. Prince F, Corriveau H, Hebert R et al. Gait in the elderly. Gait and Posture. 1997;5(2):128-35.
6. Privince MA, Hadley MC, Horbrook. The effects of exercise on falls in elderly patients. JAMA. 1995;273(17):1341-247.
7. Close J, Ellis M, Hooper R et al. Prevention of falls in the elderly trial; a randomised controlled trial. Lancet. 1999;353(1947):93-9.
8. Monane M, Avorn J, Medications and falls: causation, correlation, and prevention. Clin Geriatr Med. 1996;12(2) 847-58.
9. Kim HD. The effect of obstacle height on balance control while stepping over on obstacle from a postion of quiet stance in older adults. J Kor Soc Phys Ther. 2009;21(3):75-80.
10. Koo HM, Kim MH. The Effect of a Rollator on Plantar Pressure and Foot Balance during Gait in old-aged Adults. J Kor Soc Phys Thers. 2010;22(5):71-6.
11. Gross M, Stenvenson P, Charette S et al. Effects of muscle strength and movement speed on the biomechanic of rising from a chair in healthy elderly and young women. Gait and posture. 1998;8(3):175-85.
12. Petrarca M, Giuseppe D, Cappa P et al. Stepping over obstacles of different heights. Gait and Posture. 2006;24(3):331-41.
13. Chen H, Ashton-Miller J, Alexander N et al. Gait patterns of healthy young and old adult. J Gerontol. 1991;46(6):196-203.
14. Han JT, Lee MH, Kim K. The Study of Plantar Foot Pressure Distribution during Obstacle Crossing with Different Height in Normal Young Adults. Korean Journal of Sport Bio-

mechanics. 2008:18(2):1-9.
15. Austin G, Garrett G, Bohannon R. Kinematic analysis of obstacle clearance during locomotion. Gait and Posture. 1999;10(2):109-120.
16. Han JT, Gong WT, Yun SL. Comparison of muscle activity with lower extremity during stairs and ramp climbing of old adults by EMG. J Kor Soc Phys Ther. 2009;21(3):75-80.
17. No JS, Kim TH. Reliability of Plantar Pressure Measures Using the Parotec system. KAUTPT. 2001;8(3):35-41.
18. Lee JS, Kim YJ, Park SB. A Study of In-sole Plantar Pressure Distribution in Functional Tennis Shoes. Korean Journal of Sport Biomechanics 2004;14(3):99-118.
19. Said CM, Goldie AE, Patla WA et al. Obstacle crossing in subjects with stroke. Arch Phys Med Rehabil. 1999;80(9):1054-59.
20. Kim YJ, Ji JG, Kim JT et al. A comparison study for mask plantar pressure measures to the difference of shoes in 20 female. Korean Journal of Sport Biomechanics. 2004;15(3):83-98.
21. Jung SM. Effects of Short-Term Intensive Balance Training for the Performance Ability of Lower Extremities in the Elderly. KAUTPT. 2007;14(1):11-20.
22. Brown M, Sinacore DR, Host HH. The relationshinp of strength to function in the older adult. J Gerontol A Biol Sci Med Sci. 1995;50(A):55-9.
23. Shephard RJ. Exercise and aging: Extending independence in older adults. Gerantrics. 1993;48(5):61-4.
24. Sparrow WA, Shinkfield AJ, Chow S et al. Characteristics of gait in stepping over obstacles. Hum Mow Sci. 1996;15(8):605-22.
25. Bogey RA, Gitter AJ, Barnes LA. Determination of ankle muscle power in normal gait using an EMG-to-Force Processing approach, J Electromyogr Kinesiol. 2010;20(1):46-54.
26. McGowan CP, Kram R, Neptune RR. Modulation of leg muscle function in response to altered demand for body support and forward propulsion during walking. J Biomech. 2009;43(7)850-7.
27. Rutherford DJ, Hubely-Kozey C. Explaining th hip adduction monent variablity during gait : implication for hip abductor strengthening. Clin Biomech. 2009;24(3):267-73.
28. Kernozek TW, LaMotte EE. Comparisom of platar pressures between the elderly and woung adults. Gait and posture. 1995;3(3):143-8.
29. Hsue BJ, Miller F, Su FC. The dynamic balance of the children with cerebral palsy and typical developing during gait, Part Ⅰ: Spatial relationship between COM and COP trajectories. Gait and postrue. 2009;39(3):465-70.
30. Ye MU, Lee SD, Lee DC et al. An Analysis of walk speed and plantar foot pressure distribution with safety shoes. The Korea Institute of Plant Engineearing. 2006;11(1):51-63.
31. Park MC, Lee SY, Lee MG. Plantar foot of stroke patients while crossing obstacle of defferent heights. J Phys ther Sci. 2010;22(2):135-9.
32. Stewart L. In-shoe pressure distributaion in MBT shoe versus flat-bottomed training shoes: A preliminary study. Department of orthopedic surgery. SSC4 report.
33. Said CM, Goldie PA, Culham E et al. Control of lead and trail limbs during obstacle clossing following stroke. Phys ther. 2005;85(5):413-27.