CHAPTER V

DISCUSSION

This study sought to explore the effects of up-and downslope walking on spatial-temporal gait parameters (step length, double-support time, toe clearance, maximal sole inclination) and variability (stride length and stride time variability) in healthy community-dwelling elders. These gait variables were suggested to reflect gait instability among elderly persons (5-6, 15-21, 23, 25-30).

Only female participants were selected because they are more prone to injurious falls (23) and to eliminate gender effects (66). Each participant walked at a self-selected speed on a treadmill. Previous studies demonstrated that treadmill gait characteristics are qualitatively and quantitatively similar to overground gait characteristics (67-68). Use of a treadmill in gait study offers a number of advantages. Both physical space and number of cameras required can be reduced. The treadmill can be used to impose a predetermined speed, allowing a meaningful comparison of gait parameters between sessions. In addition, the treadmill is a practical method to manipulate slope surfaces.

Each participant walked in three walking conditions: level surface, upslope surface (ramp up 9°) and downslope surface (ramp down 9°). The self-selected speed was maintained at all walking conditions to minimize the effect of speed on gait dynamics (31). For each condition, two-hundred strides were used for data analyses. Based on a previous study, 200 consecutives strides were sufficient to compute stable gait variability (69).

Self-selected gait speed of participants in the present study (mean = 0.72± 0.25, range = 0.47-0.97 m/s) was similar to that reported by Hausdroff and colleagues (mean = 0.29±0.84, range = 0.55-1.13 m/s) (27).

Average Gait Parameters

Step length

For level surface condition, average step length of the participants in the present study (mean = 0.45±0.03, range = 0.42-0.48 m) was similar to that reported in a previous study (mean = 0.56±0.11, range 0.27-0.85 m) (25). Step length decreased both in up- and downslope walking compared to the level surface walking. There was no significant difference in step length between the upslope and downslope surfaces. In the present study, step length of the left and right leg was symmetry across the three surface conditions. Thus, changes of step length (i.e. increase or decrease) in the present study were comparable to changes of stride length in previous studies.

Leroux and colleagues (37) examined postural adaptation to uphill from 0°-5.6° in healthy young subjects. The results showed a gradual increase in stride length as the uphill slope increased. They suggested that a key mechanism of upslope walking was to lift up the swing leg by simultaneously increase in hip, knee and ankle flexion as well as an increase forward tilt of trunk and pelvis. These postural changes were accompanied by a gradual increase in stride length as the slope became steeper.

Lay and colleagues (31) examined lower limbs kinematics during upslope walking at 0°, 8.5° and 21°. They also found an increase in flexion of hip, knee, and ankle joint during upslope walking. However, there was no significant difference in stride length between level and upslope walking. Similarly, Wall and colleagues (35) showed that positive gradient (11.25°) had no effect on stride length of healthy young subjects.

It appeared that stride length was not a key controlled variable for negotiating upslope walking. Modifications of trunk, pelvis, and lower limb joint angle were primarily required to counteract the effect of gravity during upslope walking. Stride length appeared to be a derivative of hip angle. It was reported that increase in hip flexion was associated with increase in stride length and treadmill grade (37). In addition, gait speed may also affect stride length. Murry (67) found that both stride length and trunk forward tilt were pronounced at fast walking speed (2.2 m/s) as compared to self-selected speed (1.5 m/s).

Decrease in step length of participants in the present study was likely to be a cautious strategy that healthy elders used while walking upslope. It is known that one of the distinct gait characteristics elders exhibited when their state of steady was compromised was to decrease step length (5-8). It is possible that healthy elders traded off the biomechanical advantage of increasing step length during upslope walking to ensure a stable gait pattern.

Our finding of decreased step length during downslope walking showed good agreement with previous studies in young adults (34, 36-37). Leroux and Kawamura (36-37) revealed that the most conspicuous phenomenon in downslope walking was in step length. During downhill walking, the body is moved forward and downward by the mechanical effect of the slope. To counteract these gravity forces, lower limb joints (especially the knee) have to absorb more energy and break the forward momentum of the body (34). This decrease in body momentum is reflected by a progressive decrease in stride length.

Double support time

Studies in healthy young adults indicated that double support time was not affected by surface levels (31, 37). Double-support time in the present study was also not affected by walking surfaces. However, it could not conclude that healthy elders employ the same strategy with young adults. In the present study, the treadmill speed was pre-determined. Thus, participants were unable to modify their gait speed. Previous studies reported that one strategy elderly persons often use to gain stability while walking is to prolong the double-support time period (1, 70). Therefore, further study needs to investigate double support time of elders when walking on slope surfaces in the situation where gait speed can be deliberately adjusted.

Toe clearance

When walked on level surface, toe clearance of the participants in the present study (mean = 2.0±0.3, range = 2.3-1.7 cm) was slightly higher than that reported by Chiba and colleagues (18) (mean = 1.52±1.0, range = 1.42-1.62 cm) in the same condition.

As expected, toe clearance was significantly increased in upslope walking compared to level and downslope walking. An increased toe clearance during upslope walking was similar to previously published studies in healthy young adults (31, 33, 37). Prentice el al. (33) examined the transition of walking from a level surface onto different inclined surfaces (slope = 3°, 6°, 9°, 12°) by quantifying lower limbs kinematics. They found that the swing limb motions demonstrated an increased elevation of the toe trajectory during all ramp inclinations. The increases in the height of the toe began directly following toe-off and continued until heel contact on the ramp surface. This increase in toe clearance was a product of increasing flexion of hip, knee and ankle joint.

Toe clearance during downslope walking was similar to that recorded during level surface walking. Our finding was consistent with studies in healthy young adults. Redfern and colleagues (34) found only slightly changes in hip, knee and ankle joint of the swing limb during downslope walking compared to level surface walking. Unlike upslope surface, the swinging leg did not need to avoid tripping in the downslope surface. Therefore, toe clearance was unchanged when compared with level surface condition.

Maximal sole inclination

During downslope walking, participants' maximal sole inclination decreased when compared with level surface walking. There was no significant difference in maximal sole inclination between the upslope and level surface walking conditions.

Maximal sole inclination in the present study was defined as the maximal angle of the foot at heel contact relative to its horizontal line. It is generally assumed that maximal sole inclination increases as ankle dorsiflexion increases and decreases as ankle dorsiflexion decreases. However, there are situations where ankle dorsiflexion increases without change of sole inclination. For example, an increase of dorsiflexion may result from a forward move of the tibia while sole inclination stays unchanged.

Previous studies in healthy young adults demonstrated an increase in ankle dorsiflexion during upslope walking (31, 33, 37). Healthy young adults increased flexion of the ankle joint together with the knee and hip joints in order to counteract the gravity force and propel the body forward during upslope walking (31, 33, 37).

The results in the present study found that maximal sole inclination did not differ significantly between upslope surface and level surface. By visual observation from the video images, we found greater forward movement of the shank segment at terminal swing phase during upslope walking compared to level surface walking. Thus, similar to young adults, elderly participants appeared to increase ankle dorsiflexion during upslope walking but this change could not be revealed from maximal sole inclination.

Downslope walking led to a progressive backward tilt of the trunk to break the forward momentum of the body (37). It was speculated that elders decreased maximal sole inclination during downslope walking to accommodate the vertical orientation of the trunk, the hip and ankle showed a progressive decrease of flexion as compared with the level condition.

In summary, elders in the present study showed a significant decrease in step length and increase in toe clearance during upslope walking condition compared with level surface walking condition. It is speculated that decrease in step length of participants in the present study was a cautious strategy that healthy elders used while walking upslope. Specifically, healthy elders traded off the biomechanical advantage of increasing step length during upslope walking to ensure a stable gait pattern. In addition, the reduction of step length during walking on upslope surface may be due to the significant increase in toe clearance. As toe clearance increased, the duration spent in the swing phase increased. Since walking velocity was constant in the present study, participants were forced to urgently place the foot of the swing limb onto the treadmill as the supporting limb is carried backwards by the treadmill's belt. Walking on the downslope surface resulted in a significant decrease in step length and maximal sole inclination. These findings were similar to those found in healthy, young subjects in previous studies, suggesting similar strategy.

Gait variability

Stride length and stride time variability

We chose to analyze stride time and stride length variability because these variables were demonstrated to be robust indicators of gait instability and reflect motor control inefficiency (5, 15, 23, 25-30). In a specific task that requires unique demands on the neuromuscular system such as walking on slope surfaces, locomotors pattern might be adaptive. Consequently, the integrity of motor control system plays an essential role in an adaptive control movement. As a result, we sought to investigate if elders will increase gait variability when walked up-and downslope. The results found that spatial (stride length) and temporal (stride time) gait variability did not differ significantly on up-and downslope surface compared with level surface, suggesting a consistency of the central nervous system's ability in regulating gait and maintaining a steady walking pattern. It is known that task demand affects gait variability. Thus, it is possible that an unchanged gait variability observed in the present study was due to a relatively low task demand. Increase in walking difficulty (e.g. increased slope or walking velocity) may affect gait variability.

CONCLUSION

Healthy, elderly women in the present study demonstrated a significant decrease in step length and increase in toe clearance while walking on the 9° upslope surface compared to that on the level surface. Other variables did not significantly change compared to those in the level surface. It was speculated that these changes reflected a cautious gait strategy the elders employed to ensure gait stability. Given that the walking velocity was fixed in the present study, it was also possible that decreased step length was a trade off for increased toe clearance. Specifically, subjects spent a long time in swing phase to lift their foot up high (i.e. increase toe clearance). Thus, they did not have enough time to place their foot far. Walking on the 9° downslope surface resulted in a significant decrease in step length and maximal sole inclination while other variables were unchanged. Stride length and stride time variability were relatively unchanged in the present study, suggesting efficiency of the neuromuscular control system in regulating gait and maintaining a steady walking pattern.

FUTURE STUDY

The present study examined the effects of up- and downslope on mean and variability of gait parameters in healthy elderly women. Our findings provided baseline information on gait parameter adjustment of healthy elders when negotiating slope surfaces. We speculated that the different pattern of gait adjustment found in the upslope condition (as compared to healthy young subjects) were due to a cautious strategy the elders used to ensure gait stability. However, future studies needed to confirm this issue by comparing gait parameters between elders with and without balance impairment. Different degree of surface inclination/declination should also be investigated. Finally, a study design that allows gait speed to be freely modified would provide a comprehensive understanding on an adaptive mechanism of elders when walk on slope surfaces.