A FOOT AXIS FOR COP PATH OF OLDER ADULT SHORT ACCESS-RAMP WALKING STUDY

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A foot axis was developed for the investigation of whether there is any significant difference in the COP path position between uphill and downhill walking on a short access-ramp built according to the access-ramp safety-code specifications. The investigation involved the use of signalised plantar pressure video of 15 adults who performed a two-step gait on a custom-built inclined walking access-ramp. The plantar pressure images were processed to obtain the position of the COP path relative to the new medial foot axis. The findings showed that the difference in the COP path position on the plantar surface was statistically significant at the forefoot region between uphill and downhill access-ramp walking at a recommended maximum grade of 1:8. Based on these findings, more research is needed to determine access-ramp safety-grades for the elderly based on downhill walking characteristics.

KEY WORDS: plantar pressure, COP, walking slope, elderly, fall, foot axis

INTRODUCTION: The Centre of pressure (COP) path during the various phases of loading gait are calculated using pressure data which is recorded as a video clip of 100 image frames per second (Han et al., 1999; Rana, 2099). Because the pressure distribution fluctuates between trials, multiple trials are often required to obtain a representative estimate of the true plantar pressure in a person(Bus and de Lange, 2005). Therefore, the position of the COP path appears to differ between trials. Kouchi (1995) attempted to quantify the COP path by connecting a line between the soft pad at the 2nd distal phalange and the pternion (Fig 1a). The reference line was known as Kouchi foot medial axis. Based on this axis a number of studies involving neuropathic gait, muscular dystrophic gait and elderly gait were published (Han et al., 1999; Kouchi et al., 2009). In the plantar pressure video clip of elder adults the second distal phalange sometime are not available or the images are imprecise or unclear. This is due to age-related foot structural deformation such as claw foot. To overcome this issue, a new and reliable technique utilising small target is developed to determine the true position of the medial foot axis in the plantar pressure images. By placing small soft round targets on the medial foot axis of the foot before a gait trial, the markers are imprinted onto the pressure video as a “digital signal”. The targeted ends of the axis were foot anthropometric marks, namely: the 2nd metatarsal head and the pternion. These two points are the permanent reference for this new foot axis (Fig 1.b). Thus the virtual line connecting the imprint of the targets represents the position of the new true medial foot axis.

The study of gait characteristics and bipedal biomechanical dynamics on inclined walkways and stair-steps for elderlies has received much attention as falls are prevalent in this age group (Sheehan et al. 2012; Ferraro, 2010; Pavol, et al, 2001). Researchers have argued that the path of COP has a direct relationship with gait stability (Hsue et al. 2009; Winter, 1995). More importantly, authors in Hsue et al. (2009) found attributes of the displacement of COP were particularly valuable in the study of balance and postural control of cerebral palsy children. Based on the new medial foot axis marking method introduced in this paper, precision determination of the COP path relative to the plantar surface during gait for longitudinal study is now possible.

Safe access-ramp grade has been a subject of research for older adult trips for decades (Sheehan et al. 2012; Sanford et al., 1997). While authors in Sanford et al. (1997) and most local council building codes recommended a maximum grade of 1:8, the authors in Sheehan et al. (2012) suggested a ramp grade of below 1:2.7 which is almost three times greater than recommended. The use of accurate COP path and plantar pressure data collectively to study the effect of graded short ramp on walking characteristics has not been carried out in the past. It is hypothesized that the use of the new medial foot-axis on the pressure video can provide an insight into the change in COP path and pressure for these types of access ramp walking. Therefore, the objective of this investigation is to determine whether there is any significant difference between COP path and pressure data for short access-ramp uphill and downhill walking.

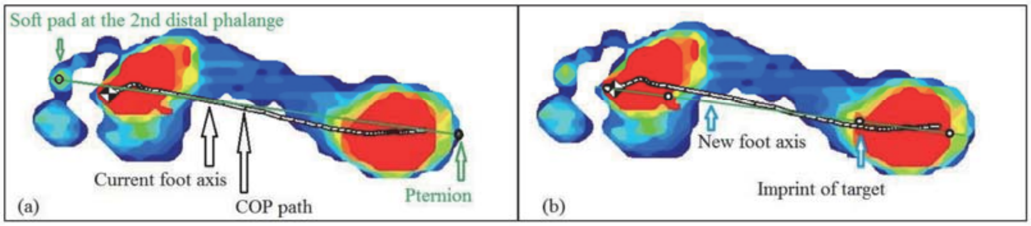

Figure 1: (a) Current Kouchi foot axis; (b) New foot axis.

METHODS: Fifteen healthy adults ranging in age between 34 and 63 (47±11 years) were recruited in the study. The participants consisted of 10 males and 5 females. Human Research Ethics Approval (USQ-H14REA156) was obtained from the University Human Research Ethics Committee. Test subjects were given instructions on the procedure of the two-step gait (Putti et al., 2001; Bus and de Lange, 2005); Bryant et al., 1999). The procedure consisted of walking normally from standing position with the feet placed comfortably in parallel on a level surface. Each participant's right medial foot axis is targeted at four locations, which included two reference landmarks: the 2nd metatarsal head and pternion of the foot (Davidson et al., 2007; Winter, 1995). The subjects started off with the left foot forward and stepped on a TekScan floor pressure mat with the right foot. Each individual was required to perform uphill and downhill walks on a custom-built ramp of 1:8 grade. The pressure video clips were checked to ensure that each subject has three COP paths that were reasonably uniform in shape for each of the inclined surfaces walked. The clips were processed in a customized image processing software. The processing involved: 1) locating the imprint of the targets; 2) depicting the new foot axis on to all the image frames in the video clip; and 3) establishing a two-dimensional coordinate reference system with the origin at the 2nd metatarsal head and the x-axis pointed towards the Pternion along the new medial foot axis.

The coordinates of the three points along the COP path were chosen for statistical comparison. These locations were: site 1 at the 2nd metatarsal head, site 2 at mid-foot and site 3 at 1.5 cm from the pternion. The measuring process involved fixing the x-coordinate of these points along the foot-axis while the y-coordinates were determined as a perpendicular distance (offset) from the foot axis to the COP path. The pressure-time-integral (PTI) and peak pressure (PP) were determined at four regions, namely: the first metatarsal, the second metatarsal, the hallux and the heel (Putti et al, 2008) using TekScan software (version 6.7) and statistical analysis was carried out in SPSS (version 22).

RESULTS: The offset values at the plantar 2nd metatarsal head and the plantar heel for the uphill and downhill walks are depicted in Figure 2. Recruits were identified as 1 through to 15 (along the x-axis). The blue (square) and green (circle) symbols represent the uphill offset value and downhill offset value at the three plantar sites respectively. Table 1 shows the foot axis-COP path offset value statistics of the new foot axis and Kouchi foot axis. As the COP path can occur at either side of the medial foot axis, the offset can have positive or negative values. In the uphill walk, the offset values were mainly positive and the offset produced negative values for the downhill walk. Table 2 shows the statistics of the PP and PTI for the selected plantar regions.

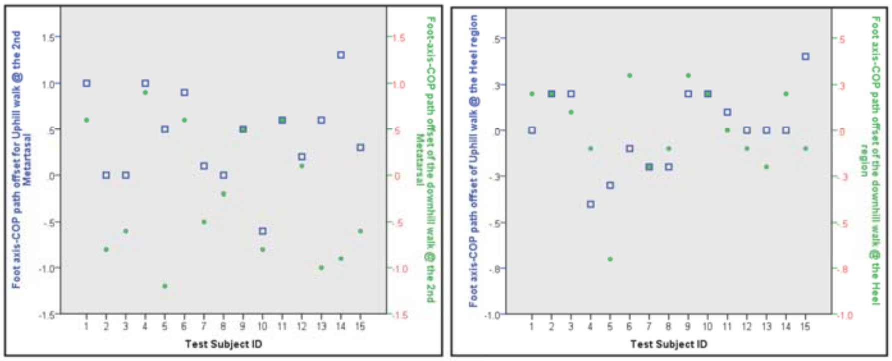

Figure 2: (left) COP offset value at the plantar 2nd metatarsal head of the uphill and downhill walking; (right) COP offset value at the plantar heel of the uphill and downhill walking.

Table 1
Foot axis-COP path offset statistics of the uphill and downhill trials

Statistical test method/plantar region	Offset difference(cm)			
Independent sample mean t-test	Mean diff	t-value	df	P (1-tailed)
a) New foot axis				
2nd_M	0.64	2.898	28	0.003
Midfoot	0.28	1.266	28	0.108
Heel	0.01	0.076	58	0.470
b) Kouchi foot axisd				
2nd_M	0.78	1.671	28	0.009
Midfoot	0.44	1.111	28	0.289
Heel	0.21	0.063	28	0.511

Table 2
Pressure data statistics of the uphill and downhill trials

Test method/plantar region	PP (kPa)					PTI (kPa s)				
Independent sample mean t-test	Mean difference	PM *(%)	t	df	P(1-tail)	Mean difference	PM* (%)	t	df	P(1-tail)
1st metatarsal region	15.8	8	0.437	28	0.331	3.8	5	0.259	28	0.399
2nd metatarsal region	51.2	14	1.291	28	0.103	22	16	1.45	28	0.079
Hallux	112.8	38	2.301	28	0.014	53.6	50	2.539	28	0.085
Heel	4.4	1	0.125	28	0.451	2.5	4	0.277	28	0.392

*PM = % of the sample mean

DISCUSSION AND CONCLUDING SUMMARY: In Table 1 the mean difference between the uphill and downhill walks were larger for the current Kouchi foot axis method. The P values were also were slightly larger for all regions. Therefore, the data of the existing technique can cause more type II errors. The type of reference foot axis used has impact on the COP offset values but has less effect on the PP and PTI value. The data presented in Table 2 shows the statistics of the new reference axis only. In the table four major plantar regions were selected for the statistical test of the effect recommended maximum ramp grade on PTI and PP. The test of the PP at the forefoot show statistical significant (accept HA:$\mu 1-\mu 2 \neq 0$, 95% CL) between values of the two walking slopes. The mean difference as a percentage (PM) of the averaged PP mean between the two samples was 38% at this region. In the PTI test, the independent sample mean test was marginally significant and the PM was also substantial at 50%. Generally, a PM value is less than 10%, thus the difference is very significant. The box plots reflect the statistical findings.

In Figure 2, all the offset values of the trials were clearly different between the uphill and downhill walks. The Figure shows that the COP path is closer to the medial aspect of the true medial foot axis for downhill walking. In Table 1, the mean difference as a percentage (PM) of the averaged offset mean was 95% at this region. The high PM value indicates that the COP path is mainly along the lateral side of the foot-axis of the uphill walk and moves to the medial side of the foot axis for the downhill walk.

Previously, it was difficult to detect the small change in the COP path based on the plantar surface for gentle uphill and downhill gaits. The proposition that the effect of common walkway gradients on COP paths are measurable using accurate plantar markers is convincing. The computerised technique developed has shown better accuracy, efficacy and improved automation. True medial foot axis can be re-established on the plantar surface, thus providing a permanent feature for future reference.

The findings show that when walking downhill on a short access-ramp, the COP path moves closer to the medial aspect at the forefoot region. Pressure data show the high impact at the hallux region. Can these characteristics affect the stability of walking for older adults adversely, where more effort is required for body balance and to lift the first distal phalange off the walking surface at the same time? We are currently examining a cohort of older adults (age 60s-70s) to search for answer to this question.

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