# CHANGES OF GAIT PATTERN ON SLIPPERY WALKING SURFACES IN SIMULATED CONSTRUCTION WORKSITE ENVIRONMENTS

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This study aimed to investigate the gait pattern when walking on potential slippery surfaces. Twelve male subjects performed level walking at their natural cadence and without slips under sixteen simulated construction site walkway conditions with different floorings, contaminants and footwear. Gait pattern parameters were collected by video cameras and were analyzed by motion analysis system (APAS). Dynamic coefficients of friction (DCOF) of the walkway conditions were determined in a mechanical slip resistant test. Significant correlations were found with the DCOF for stance, swing and stride time. Significant increase in stance time, swing time and stride time, decrease in stride length and heel velocity at contact, and slower mean propagation speed were found when slippery potential increased. Further study is suggested to provide a more comprehensive explanation of human adaptation to slippery walking surface which helps proposing occupational safety in worksite.

**KEY WORDS:** occupational slips and falls, coefficient of friction, gait preventive measures.

**INTRODUCTION:** Occupational slip and falls were the most serious causes of disability, fractures and deaths in worldwide countries. In Hong Kong, construction worksite ranked top (30.1%) in the places of traumatic injury occurrences among the reported occupational injury cases, and accidental falls was the main cause (41.1%) of hospitalized injuries (OSHCHK, 2003). Kinematics analysis of gait pattern is a tool to illuminate how human adapts to slips (Cham and Redfern, 2002). Slipping risk could be investigated by mechanical tests to analyse the available friction between combinations of walking surfaces, surface contaminants and footwear (Grönqvist et al, 1989). In this study, the changes in gait pattern on potential slippery walking surfaces without slips in sixteen simulated construction worksite environments were investigated in a human walking test. A mechanical slip resistant test of the sixteen testing conditions was also conducted to evaluate the slipping risk of the simulated walking surfaces.

**METHODS:** A survey was conducted in order to select popular floorings, surface contaminants and footwear to best simulate the local construction worksite environments. From the 150 returned questionnaires, two types of floorings, four types of surface contaminants, and two types of footwear were selected to make a total of sixteen different walkway conditions. The floorings included wood and cement. The contaminants included dry, sand, water and oil. The footwear included a type of safety shoe which was recommended by the Hong Kong Occupational Safety and Health Council, and a type of cloth sport shoe which was a kind of light-weight, low-price and popular shoe in Hong Kong and Mainland China. A mechanical slip resistant test was conducted prior to the human walking test. A pulley system (Figure 1) which allowed an adjustable horizontal drag force was used to drag a 2.5 kg-weighted shoe over the walkway conditions over a force plate (Newton et al, 2002). Weights were added gradually until the shoe slid. The horizontal and vertical reaction forces during the slide were recorded by the force plate. By dividing the horizontal reaction force by

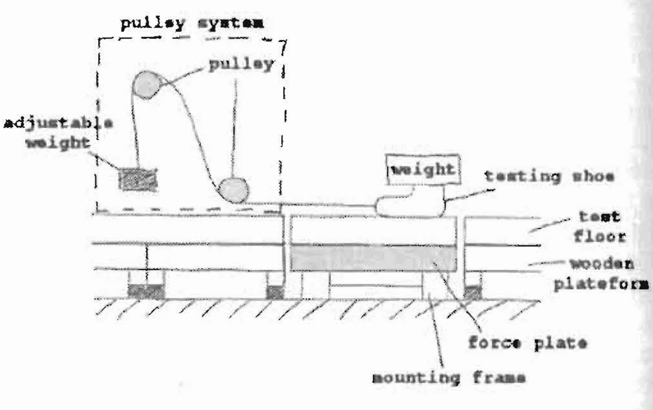


Figure 1 – mechanical slip resistance test setup

the vertical reaction force, the dynamic coefficients of friction (DCOF) were obtained. DCOF was employed as the slipping risk indicator as the heel horizontal velocity was never found to be zero at foot strike, and therefore DCOF was commonly investigated in previous studies, instead of static coefficient of friction. The slipping risks were ranked by the measured DCOF, according to the classification suggested by Grönqvist and co-workers (1989). Twelve male subjects (mean ± S.D.: age: 21.6 ± 1.3 yrs; mass: 64.5 ± 5.2 kg; height: 1.75 ± 0.06 m) participated in the human walking test. All of them were right-legged and with no injury, pain and abnormal gait during the test. Informed consents were obtained. A harness system was employed during the test. It was adjusted for each subject so that it did not affect the subject's normal gait as perceived by the subject, and it could arrest and protect the subject in case of a fall. Each subject performed ten trials on a 5-metre level pathway made by the two types of flooring plate with the two types of footwear in the sequence of dry, sand, water and oil contaminant conditions. The amounts of the contaminants were 1 L/m2 for sand, and were 0.5 L/m2 for water and oil. Four synchronized high-speed video cameras (JVC 9600, Japan) with a filming speed of 50 Hz were positioned around the walking path to capture the motion. Before each trial, subject was instructed to avoid slipping and to walk with a self-paced normal speed. Several practice trials were performed prior data collection for the subject to get familiar with the walkway conditions. Trials with slips were discarded. The sixteen walkway conditions were grouped by the slip resistant classes. Gait pattern parameters including stance time, swing time, stride time, stride length, heel velocity at contact and mean propagation speed were calculated from Ariel Performance Analysis System (APAS, USA). Pearson product-moment correlations were conducted between the DCOF and the gait pattern parameters. Multivariate analysis of variance (MANOVA) with repeated measures was conducted to determine significant differences of gait pattern parameters between groups. One-way ANOVA was conducted on each parameter provided that significant effects were shown in MANOVA. For each parameter showing significant difference among groups in ANOVA, pairwise comparisons were conducted. Statistical significance was accepted at the 95% level of confidence.

**RESULTS AND DISCUSSION:** The sixteen walkway conditions were classified into three groups (Resistant, Unsure and Slippery) according to the DCOF values obtained from the mechanical slip resistant test (Table 1). The mean value of the gait pattern parameters of the three groups were shown in Table 2.

Table 1 – group classification of the sixteen walkway conditions

| Walkway condition | | | DCOF | Class | Walkway condition | | | DCOF | Class |
|---|---|---|---|---|---|---|---|---|---|
| Wood | Dry | Safety | 6755 | Resistant | Cement | Dry | Safety | .7415 | Resistant |
| | | Cloth | .7554 | Resistant | | | Cloth | 7663 | Resistant |
| | Sand | Safety | .3284 | Resistant | | Sand | Safety | .3972 | Resistant |
| | | Cloth | .3686 | Resistant | | | Cloth | .3477 | Resistant |
| | Water | Safety | .6894 | Resistant | | Water | Safety | .6104 | Resistant |
| | | Cloth | .9368 | Resistant | | | Cloth | .7149 | Resistant |
| | Oil | Safety | .1941 | Unsure | | Oil | Safety | .5790 | Resistant |
| | | Cloth | .1404 | Slippery | | | Cloth | .3225 | Resistant |

Table 2 – mean value of gait pattern parameters of the three groups

| Gait Pattern Parameters | Resistant | Unsure | Slippery |
|---|---|---|---|
| Mean DCOF | .5881 | .1941 | .1404 |
| Stance time (s) | .790 ± .060 | .912 ± .138 | .858 ± .118 |
| Swing time (s) | .423 ± .022 | .441 ± .033 | .438 ± .030 |
| Stride time (s) | 1.213 ± 071 | 1.353 ± .160 | 1.296 ± .140 |
| Stride length (m) | 1.214 ± .08 | 1.054 ± .11 | 1.150 ± .09 |
| Heel velocity at contact (m/s) | .501 ± .168 | .316 ± .194 | .436 ± .188 |
| Mean propagation speed ($m/s^2$) | 1.006 ± .104 | .897 ± 149 | .794 ± .155 |

Significant correlations with DCOF were found for stance time (r = -.564), stride time (r = -.550) and stride length (r = .563). MANOVA with repeated measures showed significant effects on the gait pattern parameters between groups (Wilks' Lambda = .648, F = 7.385, p = .000). One-way ANOVA showed that significant differences were found in all analyzed gait pattern parameters (p < .05). For stance, swing and stride time, significant increases were found between resistant-unsure and resistant-slippery conditions (p<.05). For heel velocity at contact, significant decrease was found between resistant-slippery conditions (p<.05). For stride length and mean propagation speed, significant decreases (p<.05) were found between resistant-slippery conditions, and further decreases (p<.05) were found in slippery condition. The trends of gait pattern parameters against groups were shown in Figure 2.

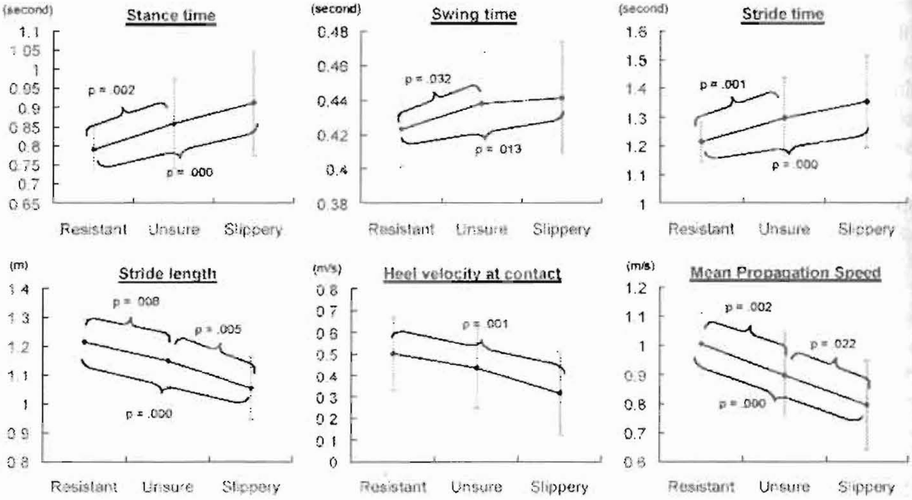


**Figure 2 – trends of gait pattern parameters against groups**

**CONCLUSION:** Stance time, stride time and stride length were found to have significant correlation with the dynamic coefficient of friction of the walkway conditions. Stance time, swing time and stride time increased as the slipping potential increased. Heel velocity at contact decreased as the slipping potential increased. Stride length and mean propagation speed showed a decreasing trend as the slipping potential increased from slip-resistant to unsure slipping potential. It further decreased as the slipping potential further increased to slippery. These findings showed the changes of gait pattern when human adapted to simulated slippery walking surfaces in construction worksite. Further studies in kinematics, kinetics, muscle activity, plantar pressure and internal joint loading are suggested.

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