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미끄럼 측정치로서의 뒤로미끄러짐

Backward Slip as a Measure of Floor Slipperiness

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ABSTRACT

To simulate an actual slip to measure floor slipperiness, slip resistance testers simulate slip in only forward direction because forward slip in the landing phase was found to be the most important factor for loss of balance. Backward slip in the take off phase was possible but was excluded in the friction test protocol because it was not dangerous. However, backward slip was tested in the friction test protocol without any theoretical background of the significance in generating dangerous slips and falls and was proven to be as good as forward slip in measuring floor slipperiness. Therefore, this study was designed to investigate the significance of backward slip in generating dangerous slips and falls with different combinations of floor and shoe sole. The results showed different tendency of backward slip in take off phase being significant in generating dangerous slips and falls because backward slip in the takeoff phase affected gait pattern disturbances seriously, resulted in dangerous falls. Fast toe velocity increased the severity of backward slip and confirmed the significance of backward slip in generating dangerous slips and falls. As a result, this study recommends the utilization of backward slip in the measurement of floor slipperiness.

Keywords: backward slip, forward slip, gait pattern, floor slipperiness, toe velocity.

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1. INTRODUCTION

In 1997, the National Safety Council reported in the Accident Facts that slips and falls accidents were the second leading cause to unintentional-injury deaths, including 14,000 deaths in 1996, next to motor vehicle accidents with 43,300 out of 93, 400 deaths. Significant economics loss was also unavoidable due to slips and falls accidents. To reduce these accidents, biomechanical and tribological approaches have been used most often.

For biomechanical approach, Perkins (1978) used the ratio between horizontal and vertical force components (H/V) on oil-covered steel to investigate where in the walking step slip was most likely to occur. The results showed that forward slip in the landing phase was the main factor for loss of balance. Backward slip prior to forward slip in the landing phase or backward slip in the take off phase was possible but in no case was slip dangerous. However, depending on the contact force/friction relationship, backward slip might start early in the take off phase when H/V was relatively low but vertical force was high, perhaps resulting in dangerous slip. Strandberg and Lanshammar (1981) also measured biomechanical data including H/V ratio on soap-patched floor to investigate the mechanics of slipping accidents. The results also indicated that forward sliding shortly after heel strike (the landing phase) was the main factor for "fall" (stopped by the safety harness) and "slip-sticks". Backward slips just before toe-off were considered irrespective to skids because they never resulted in falls, not even loss of balance.

For tribological approach, Strandberg and Lanshammar (1981) recommended that slip resistance testers reproduce important biomechanical parameters related to crucial gait phases. Of many biomechanical parameters, foot angle, contact force at the shoe, vertical force, heel sliding velocity, and contact time and normal time derivative were essential to simulate an actual slip by slip resistance testers. The articulated strut type slip resistance testers have been used to simulate slipping mechanism under the knee down to test various interactions between the shoe and floor.

To simulate the actual slip, slip resistance testers simulate slip in only forward direction (Perkins and Wilson, 1983; Grönqvist et al., 1989; Ertas et al, 1990) because only forward slip was found to be an important factor in generating dangerous slips and falls. However, Wilson (1990) simulated both forward slip and backward slip to measure floor slipperiness without proving theoretical background of backward slip being as important as forward slip in generating dangerous slips and falls. More surprisingly, the results showed that backward slip was found to be as significant as forward slip in measuring floor slipperiness because they both gave a realistic prediction of wear performance with correlation coefficient of 0.94.

As a result, in real slipping experiments with human subjects (Perkins, 1978; Strandberg and Lanshammar, 1981), backward toe slip was not used to measure floor slipperiness because it did not provide a firm evidence in generating dangerous slips and falls except the possibility of danger in the take off phase. However, in slip simulation experiments with slip resistance testers (Wilson, 1990), backward slip was also found to be responsible to generate dangerous slips and falls like forward slip. In other words, the biomechanical study of the possibility of dangerous backward slip in the take off phase should have been investigated to fill the gap of utilizing backward toe slip in measuring floor slipperiness in the tribological study. Therefore, this biomechanical study was designed to investigate the possible significance of backward slip in the take off phase in generating dangerous slips and falls. In addition, a new approach was used to investigate which slip was significant enough to generate dangerous slips and falls instead of H/V ratio.

2. METHOD

2.1 Subjects

Ten male university students participated in this experiment. The mean height was 179.3 cm (±7.10 cm) and ranged from 170.2 to 190.5 cm. The mean weight was 74.2 kg (±7.58 kg) with a range of 60 to 80 kg. The mean age was 24.9 years (±4.77), ranging from 19 to 35 years old.

2.2 Apparatus

The ExperVision motion analysis system with three video cameras was used to collect 3 dimensional biomechanical data with 60Hz data collection.

The fall arresting system (Ertas et al., 1989) was used to protect subjects from a possibly dangerous fall. The overall function of the system is to allow a subject, wearing a full-body harness, to walk under experimental conditions with little or no restrictions. A lack of restriction is achieved by the fully automated overhead suspension that uses low force actuators to ensure the suspension is largely imperceptible. Whenever an imbalance is detected, the system immediately arrests the fall and discontinues its motion. The speed of the fall arresting rig was fixed at 1.33 m/s, which is the closest velocity the rig could simulate compared to the normal walking velocity (1.36 m/s) for male adult (20 to 59 years old) by Waters et al. (1988).

Two sample floors were used: oily plywood and oily vinyl tile. Eight vinyl tiles (30 x 30 cm) were mounted on a piece of plywood. To simulate oily floor surface, a high viscosity oil (SAE 30) was applied on each floor sample. The dimensions of the simulated floor were 250 x 30 x 2.5 cm. The simulated floors were mounted in a shallow pit, so that the floor surface height would be continuous with the laboratory floor and no tripping hazards would exit. For reference, floor slipperiness by dynamic coefficients of friction (DCOF) for oily plywood and oily vinyl were measured (Myung and Smith, 1997) and were 0.43 and 0.11, respectively. To reduce the visual effect of floor materials, the color and contrast for all floor materials were similar.

2.3 Procedure

Ten unpaid volunteer subjects participated in the study. Retro-reflectors were attached at the anatomically significant body positions defined by Winter (1992) for the collection of biomechanical data: heel, toe, ankle (lateral malleolus of fibula) and knee (lateral femoral epicondyle) of the subject's left side. The heel and toe targets were placed on the outer-edge of the shoe. All subjects wore the same shoes (available in a variety of sizes) with a PVC sole in order to have consistent frictional values. Prior to these experiments, each subject was given an opportunity to walk around the laboratory to familiarize himself at the pace of his normal walking speed. The equipment layout is shown in figure 1. The walkway track was similar to a 400-meter running track with a circumference of approximately 25 meter. The simulated floors were placed in a 2.5 m straight section of the walking track. The arrow indicates the direction of progression. Subjects were then asked to walk across the floor samples with wearing a harness attached to the fall arresting rig. Data collection was started immediately after subjects crossed the photo cells and lasted for 3 s. Immediately before the left-side photo cell in the subjects direction of progression, a foot print was placed for subjects to step on with the left foot. Subjects stepped on the arranged floors with their right foot after crossing the photo cells. Each subject had 4 (2 floors x 2 replications) trials of walking for the study. To reduce the learning effect, each subject walked different floors on different days with at least one day break between experiments. Before walking on each oily floor surface, a high viscosity oil (SAE 30) was brushed on the left floor surface before each walk to achieve the same viscosity. While the subjects were walking along this path, they were to keep their eyes on the front wall and to try to maintain the speed that they practiced.

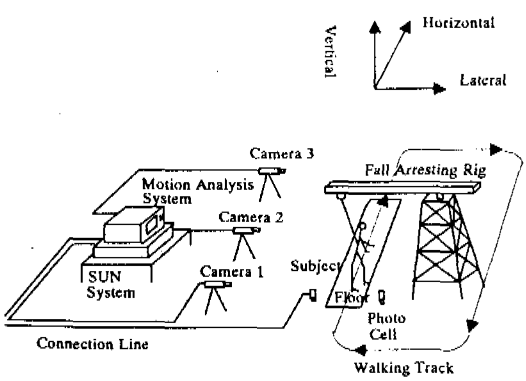

Figure 1. Equipment Layout

3. RESULTS AND DISCUSSION

3.1. Slip Identification

First of all, two plots were developed with x-axis as horizontal displacement (direction of progression) of the heel/toe and y-axis as lateral displacement of the heel/toe and vertical displacement of the heel/toe to find what really happened during each walking trial. Three types of slips were found: no slip (normal walking), forward slip, and backward slips.

Figure 2 shows a normal walking plot. The heel contacted floor, the foot flattened, and the toe took off. Therefore, the distance between each spike represents a full gait cycle (stride length). The 3 second data collection was enough to have at least 2 heel contact points for each walking trial and the second heel contact (b) was used for data analysis for the study. Unusual gait patterns before the spike (a) and after the spike (b) were expected because the subjects walking track was

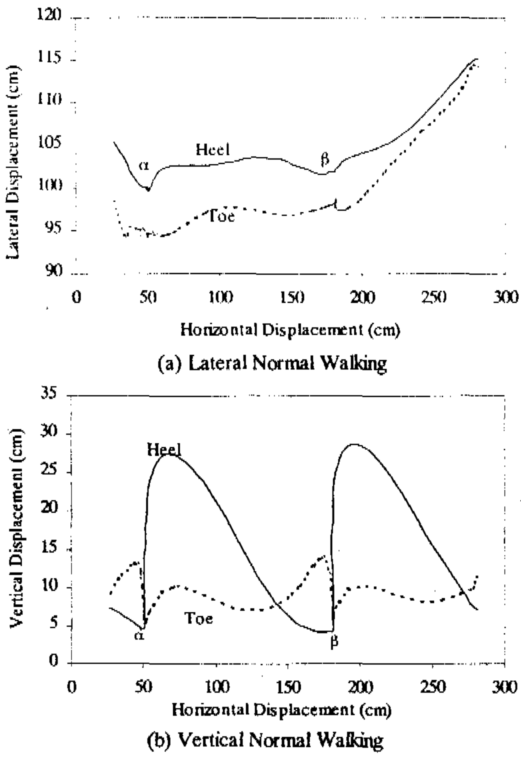

Figure 2. Normal Walking

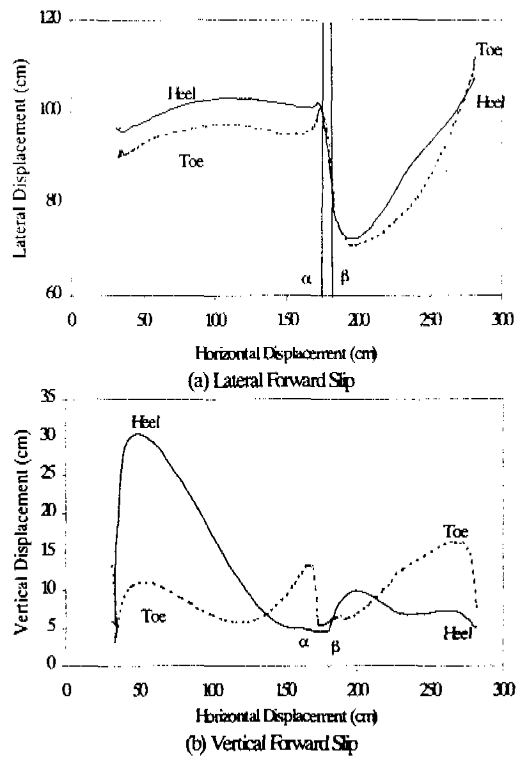

Figure 3. Forward Heel Slip

not exactly straight line as shown in figure 1.

This is a typical walking pattern without a slip because no abnormal walking pattern is found around the second spike. unusual walking pattern, a long lateral displacement of the heel. Compared figure 2 (b) to figure 3 (b), vertical displacements of toe and heel confirmed the unusual walking pattern. When the heel contacted the floor around (α), the frictional force between the heel and the floor was not enough to have a normal walking pattern.

Figure 3 shows a forward slip plot. There exist two heel contacts and the second spike includes a very Instead, the heel started sliding while the foot was flattening in the landing phase. At the same time, the unbalance between forwardly moving upper body and backward sliding lower body made subjects fall down. As soon as the weight was applied to the rotational suspension arm of the rig due to loss of balance, the rig arrested the collapse and discontinued its motion. A wild heel movement after the point (β) was expected because the rig arrested the sliding and the foot went back to the original walking track.

Figure 4 shows a backward slip in the take off phase. Neither backward nor forward slip happened from the beginning of the landing phase to the end of the stationary phase. At the take off, the toe pushed the floor backward for the body to move forward. Without enough frictional coefficient, the backward pushing by the toe could not create the opposite propellant force to move forward. Instead, the toe continued to slide backward from (α) to (β). This backward slip proved that previous studies (Perkins, 1978; Strandberg and Lanshammar, 1981) failed to show dangerous backward slip in generating the loss of balance in the take off phase, resulted in fall.

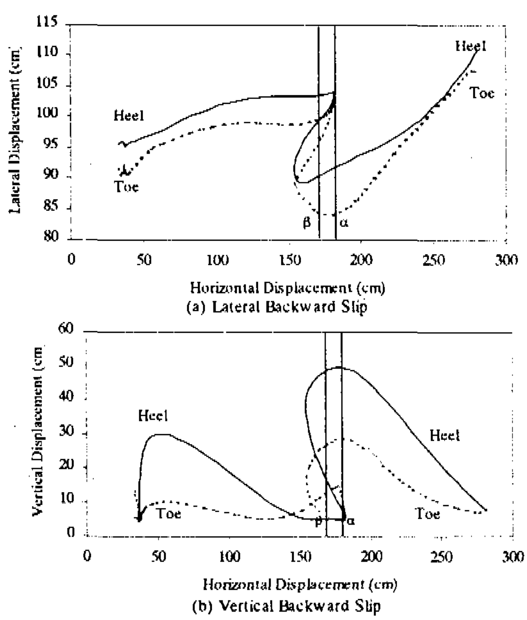

Figure 4. Backward Toe Slip

After identifying slip start and slip stop points from all slip types, slip distance was calculated. To accommodate lateral component of slip, the resultant slip distance was calculated. The formula for slip distance (SD) was as follows:

$$SD = \sqrt{(X_2 - X_1)^2 + (Z_2 - Z_1)^2}$$

where x and z represent horizontal and lateral directions as shown in figure 1. Resultant toe velocity at the point of toe off the floor was also calculated by the following equation:

$$\text{Toe Velocity} = \sqrt{V_x^2 + V_z^2}$$

where Vx and Vz are the toe velocities in the horizontal and lateral directions, respectively. To calculate the toe velocity for each direction, the difference of the foot displacement of 1/60 (0.017) second before (X_{i-1} or Z_{i-1}) and after (X_{i+1} or Z_{i+1}) the toe off the floor was divided by the elapsed time (2△t).

3.2 Significance of Backward Slip

The significance of slip can be reevaluated by the human reactions due to different slipping distances. According to Strandberg and Lanshammar (1981), subjects were either unaware of the sliding motion (mini slip) or regained balance — without apparent gait pattern disturbances (midi slip) and during large compensatory swing-leg and arm motion (maxi slip). The near-fall, maxi slip, had an average sliding distance of about 10 centimeters. As the subject's reaction approaches to fall, the significance of slip increases. To determine the significance of slip, table 1 shows the mean slip distance and standard deviation with respect to different slip types.

Table 1. Mean and standard deviation for slip distance (unit: cm)

Floor	Dcof	n	Backward	n	Forward
Oily Plywood	0.43	5	9.6±2.9	5	9.4±4.5
Oily Vinyl	0.11	5	13.8±4.8	9	8.9±4.1

The number of forward slip (5 on oily plywood and 9 on oily vinyl) was greater than the number of backward slip (5 on oily plywood and 5 on oily vinyl). The mean slipping distances showed that subjects experienced apparent gait pattern disturbance, resulted in dangerous falls, only stopped by the rig. In other words, backward slip in the take off phase in this study was found to be a significant factor for the measurement of floor slipperiness. On oily vinyl, even longer mean slipping distance was measured than forward slip in the landing phase. This longer backward slip on oily vinyl might indicate more severe effect of backward slip on the measurement of floor slipperiness as floor slipperiness increased. This backward slip also proved that previous studies failed to show dangerous backward slip in the take off phase. The possible reason for not having shown dangerous backward slip in previous studies was because the experimented floor surfaces (oil-covered steel and soap patched floor) were not slippery enough to generate dangerous slips and falls. In other words, the frictional coefficients for oily plywood and oily vinyl were found to be low enough to create dangerous backward slip early in the take off phase. Therefore the possibility of the dangerous backward slip in the take off phase was found to a fact on more slippery floors than previous studies so that backward slip in the take off phase should be incorporated into the protocol of measuring floor slipperiness.

Table 2. Mean and standard deviation for toe velocity at toe push (unit: cm/sec)

Floor	Dcof	Toe Velocity
Oily Plywood	0.43	32.8±13.8
Oily Vinyl	0.11	58.5±29.5

Another important biomechanical factor, toe velocity, was also measured and is shown in table 2. Toe velocity on oily vinyl was faster than toe velocity on oily plywood at toe push, right before backward slip started. Compared to heel velocity in forward slip, toe velocities were faster than the preferred testing velocity of 10 to 20 cm/sec in floor slipperiness measurement (Redfern et al., 1991). On the other hand, toe velocities on toe push were slower than heel velocities (Myung and Smith, 1997) on oily plywood (66.9 cm/sec) and oily vinyl (93.5 cm/sec), respectively. This might confirm previous studies of the significance of forward slip in generating dangerous slips and falls because of higher heel velocity over toe velocity. However, toe velocities in this study was absolutely higher than the recommended heel velocities of 10 to 20 cm/sec on dry surfaces and significantly disturbed normal gait pattern, resulted in dangerous slips. In other words, toe velocity ranged from about 30 cm/sec to 60 cm/sec was significant enough to have an effect on normal gait pattern change so that toe velocity was found to be another factor in generating dangerous slips and falls.

As a result, as floor slipperiness increases, the number of significant slips increases as expected. As Perkins mentioned (1978), backward slip, early in the take off phase, perhaps resulted in dangerous when H/V was relatively low but vertical force was high depending on the contact force/friction relationship. For this study, oily plywood and oily vinyl proved that backward slip was significant in generating dangerous slips and falls because subjects lost their balance, resulted in falls. In other words, backward slip in the take off phase in this study was found to be an influencing factor for the measurement of floor slipperiness because all backward slips resulted in falls, stopped by the rig. The possibility of the dangerous backward slip in the take off phase (Perkins, 1978; Standberg and Lanshammar, 1981) turned out to be a fact of dangerous backward slip in the take off phase. Faster toe velocity also confirmed the significance of backward slip in generating dangerous slips and falls. The impact of dangerous slips and falls by backward slip might be less than that of forward slip because of lower toe velocities but the impact was still there to influence the severity of backward slip. Therefore, backward slip should be incorporated into the protocol of measuring floor slipperiness.

4. CONCLUSIONS

This study found that previous studies had not shown the important characteristics of backward slip in measuring floor slipperiness. The significant findings are as follows:

(1) Backward slip in the take off phase was found to be another important factor for the measurement of floor slipperiness because all backward slips resulted in dangerous falls, stopped by the rig. Toe velocities increased the severity of backward slip with greater than toe velocities on dry surfaces. This confirmed the significance of backward slip in generating dangerous slips and falls.

(2) Since the significance of the backward slip in the take off phase was found to be very important, backward slip should be recommended to be a measure for the friction test protocol if slippery floor surface is to be measured.

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