《연구논문》

The History of Slip and Fall Accidents

Dal Ho Son *

ABSTRACT

Recorded injury identified the role of falls in producing injury througout all segments of the nation. The Economic and social costs arising from falls has been established in numerous sources, both nationally and from the international literature. Recorded injury also indicated the potential features of falls, the need for a basic understanding of the energy exchange mechanism involved and the subsequent rehabilitation processes required. It appears unlikely that any other major cause of injury has an etiology so little researched and consequently, so little understood, which in turn has prevented the development of an intervention strategy or a scientically based control technology of falls. This paper will emphasize how the postural changes of foot are related to slip/fall severity in different environmental conditions. Likewise, we will examine the whole slip/fall cycle through the biomechanical parameters involved in a range of walking speed and floor slipperiness

Introduction

Despite over three decades of data collection on the occurrence of falls, literature on the basic understanding of falls is sparse. The field of behavior that includes falling and slipping is ill-defined and is not adequately described by any common phrase. However, this paper will use the phrase "falling and slipping," and "falls" is not taken in the common use of the word which implies a transfer of energy between a person and the built environment, but rather "falls" will be used to imply the loss of equilibrium and/or the subsequent recovery from that loss. It appears unlikely that any other major cause of injury has been etiologically researched so little and, as a result, is so little understood, thereby preventing the development of a scientically based control technology of falls.

Falling is an intrinsically dangerous activity with the implication of an uncontrolled exchange of energy between a subject and the physical environment. It is, perhaps, for this reason that most investigations of falling have concentrated on a statistical or epidemiological approach, or on physical testing of components of the

* Keimyung University

footwear material, surface characteristics, contaminants or lubricants, etc.

Another thing which should be noted is that, despite considerable work, there is very little agreement on the basic principles for measuring the footwear:floor surface characteristics. For example, in 1983, Strandberg [4] identified over 70 devices reported in the literature which used a very substantial number of various approaches to measuring friction. Indeed, even the relative significance of static versus dynamic friction is still being debated. Tisserand [5], in 1969, found that its rank order correlation with subjective judgements of slip resistance was negligible for static measurements and very high for dynamic measurements.

Also what should be noted is that, up to now, many studies have established the significance of the slip in falling. Furthermore, it was suggested that the majority of dangerous slips occur with the leading foot moving forward, during the touch down phase of the stop cycle, rather than involving the lagging foot moving backwards during the push-off cycle. Under certain circumstances, these slips develop into uncontrolled sliding which in turn leads to the most common type of fall. However, a larger number of slips are clearly stopped at a distance of a few centimeters or less. Many studies, and design interventions, for example, footwear design, have attempted to prevent the start of slipping by producing very high frictional materials. Our study reports on the relationship between foot attitude, two-dimensional slip patterns, and the forces involved through the whole of the slip:stop cycle for a range of walking speeds, and floor slipperiness.

Method

Ten male students were selected from the student population. Even though there are differences in biomechanical factors betweeen males and females, only male subjects were used in this experiment in order to control the size of this study. Furthermore, an attempt was made to insure that the selected subjects represented the range of the population with regard to height and weignt.

The subject was supported by a whole body harness(Figure 1) which is suspended by a damped mechanism to provide protection, should a slip or trip lead to a fall. The rig(Figure 2) provides the capability of adjusting the speed to match the subject's. The experimental treatments are continuous, providing long exposures. This exposure is intended to allow the use of surfaces with coefficients of friction which are more normally met in practice.

The "EXPERTVISION" MOTION ANALYSIS SYSTEM was used for the collection of three-dimensional data(Figure 3). The motion analysis system consists of two video cameras, two video recordes, digitizer, monitor, and a "SUN" workstation associated with the necessary software for target tracking and data analysis. This system provides a data collection rate up to 200 fps.

The force exerted between the shoe and the ground was measured by means of Multicomponent Force Measuring Platform, manufactured by Kistler Instruments. The plateform itself was mounted on a concrete block set into the laboratory walkway, which allowed the maximum natural frequency to be obtained. Collected data were converted with A/D board and "ARIEL" DATA COLLECTION SYSTEM. This system provides 16 A/D board channels with the software for data receiving.

Ten subjects, who were supported by whole body harnesses, were walked in a race track configuration, arranged such that, during the data collection portion of the experimental treatment, they walked a straight line(Figure 4). Subjects wore retroreflectors at significant anatomical indicators such as heel, toe, ankle, knee, hip, shoulder, elbow, and wrist.

High and low friction conditions were established by the use of a greased or ungreased steel plate positioned immediately prior to the piezo-electric force plate. The subjects were arranged in a randomize order for two

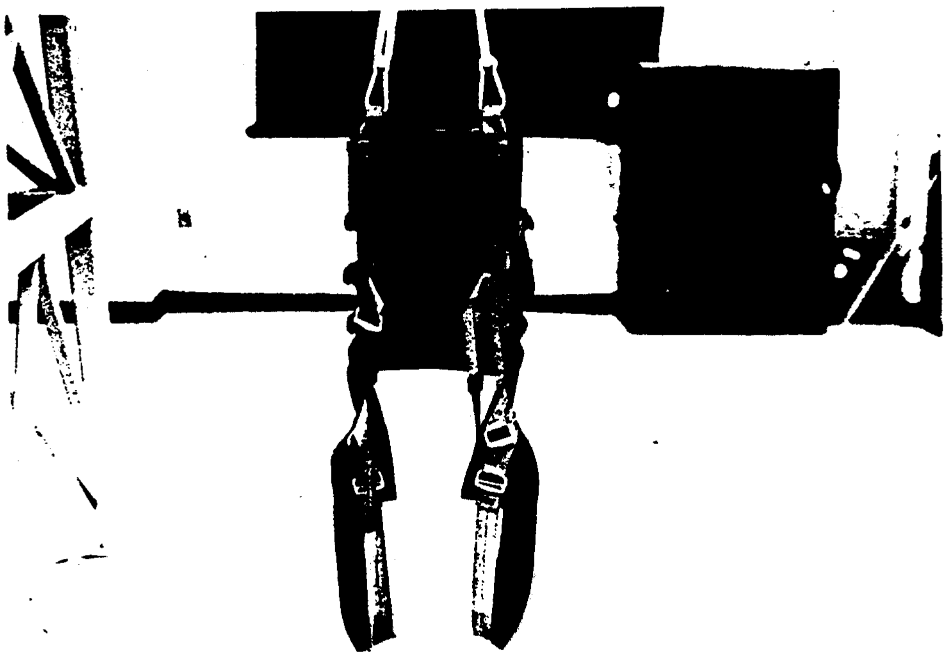


Figure 1. Subject harness of rig system

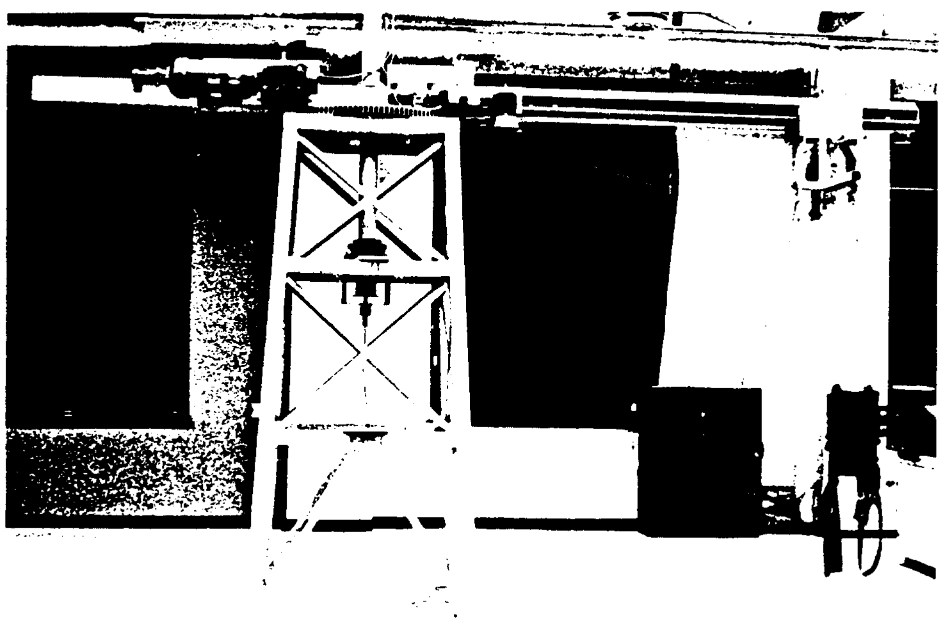


Figure 2. Fall prevention rig for subject safety

Figure 3. "Expertvision" motion analysis system

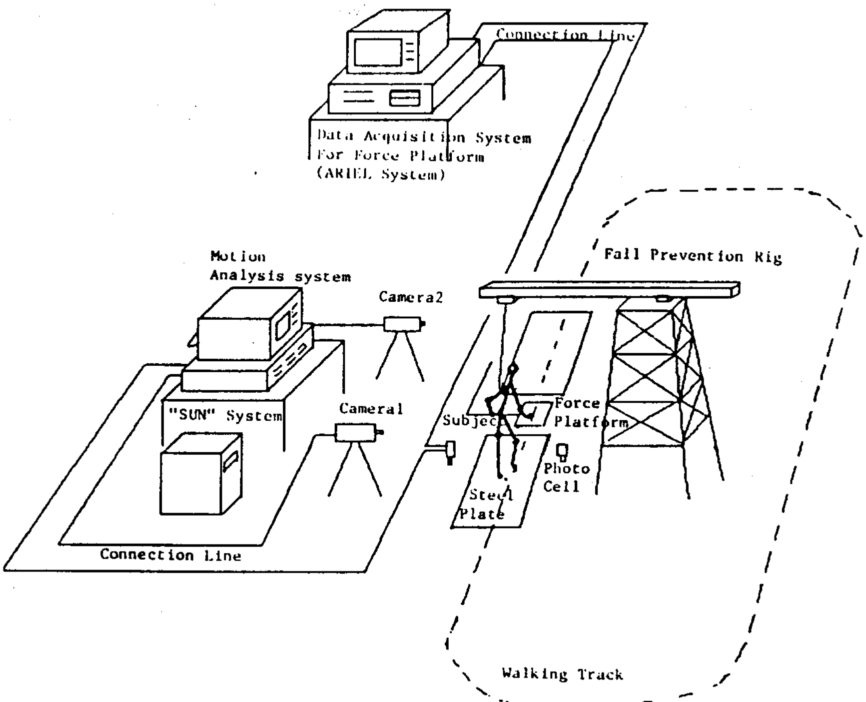


Figure 4. Equipment layout

conditions of floor slipperiness and two walking velocities(4 km/hr and 6 km/hr).

The displacement data were normalized for different walking velocities to allow times to be used for comparisons, for example, the sampled data which has a different frame in a fixed range such as from heel-down to toe-off. This transformation was carried out in order to remove the effect of change in velocity which would result form the higher speed of locomotion. The algorithm in our program, written with "C" language, using a linear interpolation technique generates the time units into 100ths of the time from heel-down to toe-off of the same foot.

As to the validity of the Rig System, our previous experiment showed that the degree of influence is dependent on the subject; however, in all cases, the use of preliminary warmup trials appeared to remove this kind of influence of the Rig.

Results

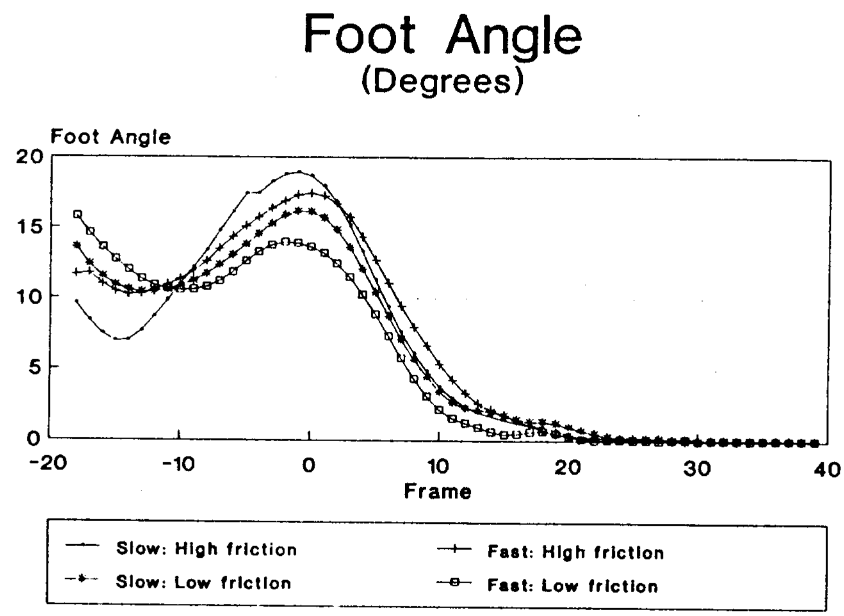
A variety of mechanisms appear possible which would explain why a microslip does not develop into a slip or a slide. Some of these mechanism concern the distance the subject slipped, and foot attitude. Some mechanisms for correcting the foot attitude in the slip/fall accident will include the coupling vetween the foot and the floor; a manipulation of the Fx/Fy ratio, a manipulation of the velocity of the heel, a change in the ratio of the angle between the foot and the horizontal.

"Foot angle" has proved to be an important variable because of its influence on the contact area [1,3,4]. Hence, striking at a "correct angle" is most important part in safe walking. Figure 5 shows the average foot angle for each experimental condition around the heel contact point. The data was normalized and averaged for each value for ten subjects in each experimental condition. At the point of contact this angle was about 19 degrees to the horizontal for slow:high friction, 17 degrees for fast:high friction, 16 degrees for slow:low friction, and 13 degrees for fast:low friction. However, these values are smaller than the value suggested by Strandberg [4]. What is significant, however, is similarity between the rate of change of foot:floor angles, measured against normalized time for all conditions. In Figure 5, it can be seen quite clearly that, in all conditions, this change occurs with essentially the same slope. This suggests that the subject is not attempting to deal with the reduced friction by more quickly lowering the foot in order to make floor contact and increase friction.

The foot angles at slip start(Table 1) were 7.5 degrees for slow:high friction, 7.3 degrees for fast:high friction, 9.5 degrees for slow:low friction, and 8.7 degrees for fast:low friction, respectively. This result shows that there is more influence from floor slipperiness than from walking velocity for the foot angles at slip start.

The so-called "Time interval for complete touchdown of the foot," i.e., the time interval between heel contact and complete touchdown of the foot, is shown in Table 1. This value was 8.2 frames for the slow:high friction, 8.1 frames for fast:high friction, 16.7 frames for slow:low friction. and 14.3 frames for fast:low friction, respectively. The sharp distinction can be seen between the slippery and non-slippery condition. That is, in the slippery condition, the time needed to complete foot contact is greater than in the non-slippery condition. Evidently, in most cases of a slippery condition, we have some kind of a slip or slide. Thus, we have foot instability; consequectly, requiring more time to achieve a stability or complete touchdown of the foot.

In most of the times, when a subject approaches some floor conditions like a slippery floor, he attempts to predict the condition of the floor. Therefore, he can manipulate the foot motion in order to reduce an unexpected accident. In order words, he tries to reduce the approach velocity of the foot touching down prior to contact, irrespective of the overall walking speed. Results of the current experiment(Figure 6) show that at the point of contact this velocity was about 150 cm/sec for a slippery condition, and 70 cm/sec for a non-slippery condition.



Frame 0 indicates heel contact point

Figure 5. Normalized and averaged foot angle in four experimental conditions

	Foot angle at slip start (Degree)		Time for complete touch (Frame)		Heel velocity at slip start (cm/sec)	
	Mean	Std.	Mean	Std.	Mean	Std.
Slow High friction	7.5	2.2	8.2	2.1	76.8	23.7
Fast High friction	7.3	3.1	8.1	2.9	78.4	29.2
Slow Low friction	9.5	2.7	16.7	3.5	88.4	31.4
Fast Low friction	8.7	2.1	14.3	3.3	101.4	34.5

Table 1. Parameter estimation for experiment condition averaged over 10 subjects

This result shows the difference between slippery and non-slippery conditions around the heel contact point. Furthermore, it can be noted that after heel contact in the fast:low friction, this value which is higher than for the other conditions. This result might be due to the fact that, at the time after heel contact in the fast:low friction, still we have some degree of a slip or slide due to the experiment condition.

In the current experiment, the heel velocity values at slip start were 76.8cm/sec for slow:high friction, 78.4 cm/sec for fast:high friction, 88.4cm/sec for slow:low friction, and 104.1cm/sec for fast:low friction. Seemingly, a little gap exists between a slippers and non-slippery condition. That is, we have a higher heel velocity at the start of a slip in a slippery condition rather than in a non-slippery condition. However, the non-parametric

Mann-Whitney test showed that there is no significant effect in the walking velocity(Alpha = 0.57) and floor condition(Alpha = 0.19).

The expression "Fx/Fy" by relating the forward force to the vertical force in a manner analogous to the calculation of friction was termed the utilization of friction [4]. Figure 7 was achieved with normalizing and averaging the divided value of the horizontal force(Fx) by the vertical force (Fy) for each experimental condition. Peak 1 in Figure 7 is usually caused by the impact force of the heel tip against the force platform and appears to have a forward direction as a result of approach velocity of the heel to the ground [1,2,4,6]. Peak 3 and 4 are both in a forward direction, being caused by the main forward force which accelerates the motion of the body and leg. In our study, peak 3 and 4 were sometimes merged. Although still less than 0.1 second after heel contact, and with only the back of the heel in contact with the ground, the vertical force rose and a significant proportion of the body weight was applied through the heel tip.

In the present experiment, the relationship shown in Figure 7 esssentially follows that of previous experimenters from Perkins onward. However, it was verified that in all cases the ratios in the present case were lower. In the slippery condition, the highest peak in each case occurred later in the cycle than for the non-slippery condition. This fact supports that, in a slippery condition, a slip/fall possibility exists in a few milliseconds after heel contact, while, in a non-slippery condition, a slide potential is higher just after heel contact.

Furthermore, the result of our experiment indicated that, in slow walking, there is a backward slip/fall possibility, which was not found in the fast walking treatment. However, the absence of the backward slipping in fast walking is considered due to the short duration of the heel contact time.

Although Strandberg [4] and others have pointed out that this peak value of Fx/Fy indicates the point at which a slide may most likely occur, it is clear that the ratio does not, in fact, identify the amount of friction which is available at that time. This would require the calculation of friction between the specific floor:shoe

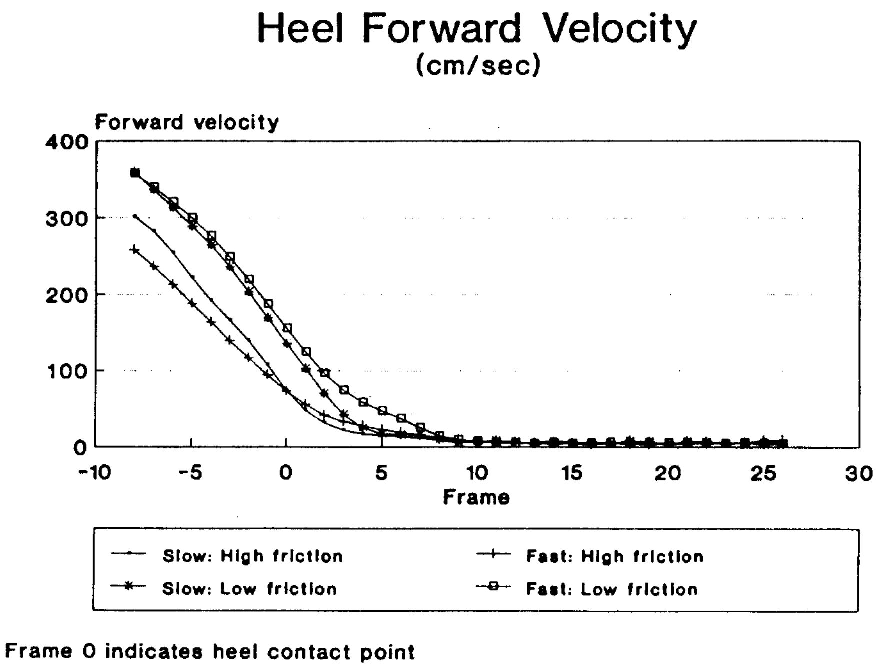


Figure 6. Normalized and averaged heel velocity in four experimental conditions

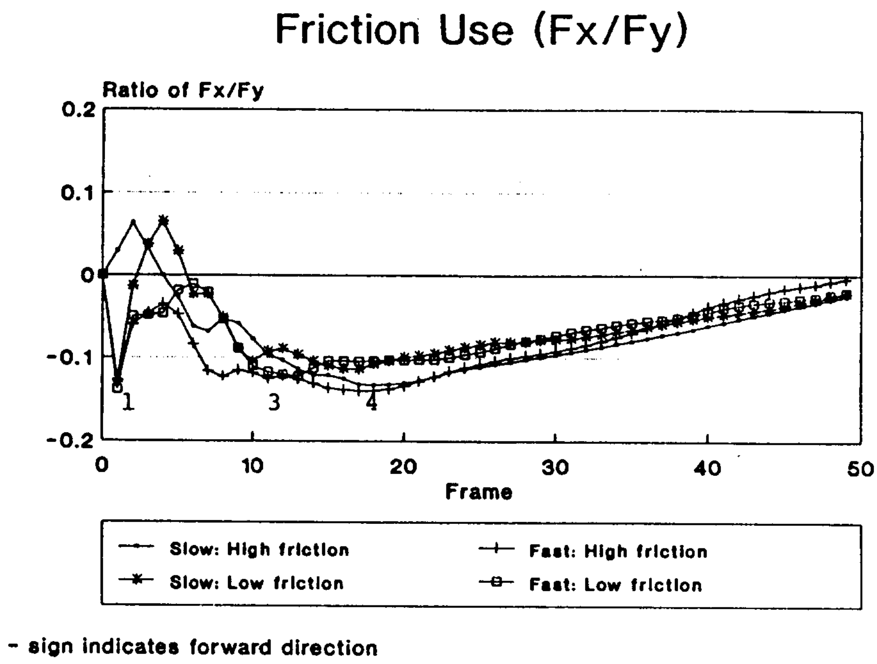


Figure 7. Normalized and averaged Fx/Fy in four experimental conditions

conditions at that particular velocity and Fy. That is, it is not possible to derive from such a ratio whether the reduction in ratio achieved by a subject approaching a slippery surface, in fact, is sufficient to reduce the risk of slipping to that of the non-slippery condition.

Evidently, it appears that Fx and Fy are related. This relationship can be examined in Figure 8 shows one example of Fx and Fy. In this figure, three distinct patterns can be distinguished. At first stage, there is the approximately linear relationship between Fx and Fy. This occurs in the interval from the heel contact to the complete touchdown of the foot. Once the foot touches down, Fx is change from forward to backward while Fy remains constant. And forms can be charged with the second stage of the relationship. Finally, the Fx and Fy again have a linear relationship, which might be due to the leaving stage of the foot. Thus, as have seen in this Figure, both parameters appear to have some relationship, even if the exact type of relationship is hard to find. Hence, it is hard to draw a conclusion from such a ratio whether the change in this value affects the slip/fall severity. That is, Fx/Fy can not be the absolute index for the slip/fall possibility.

Conclusions

The following points were summarized from the results.

1. There is a similarity between the rate of change of foot:floor angle, measured against the normalized time for all conditions. This similarity would suggest that the subject is not attempting to deal with the reduced friction by lowering the foot more quickly in order to make floor contact.

2. The heel forward velocity varied between slippery and non-slippery conditions. The reason for this variation can be considered to be the change of the swinging time and the doublesupport time of the leg. In order words, in the case of a slippery floor, postural instability causes subject to increase the double-support time, by

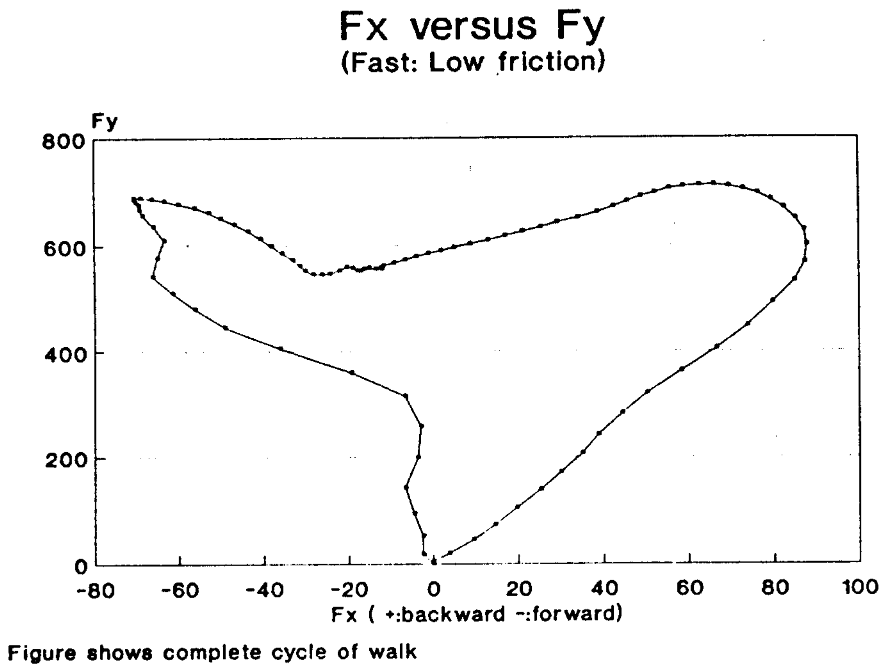


Figure 8. Example of Fx versus Fy

reducing the swinging time. That is, around the moment of heel contact in a slippery condition, most subjects attempt to make foot:floor contact as quickly as possible in order to cover body unstability due to the slippery floor.

3. Although many authors have pointed out that the peak value of Fx/Fy shows the point at which a slip/fall may most likely occur, it is obvious that the ratio does not identify the amount of friction which is available at that time. In other words, it is not possible to derive from such a ratio if the reduction in such a value is sufficient to reduce the risk of slipping.

So far, many investigators of slipping accidents have not considered slips and falls to be complicated phenomena from both tribological and biomechanical aspects. Therefore, the literature exhibits quite a few slip-resistance measurement methods which demonstrate how an existing and original approach can be invalidated or seriously damaged by inattention to basic principles of research methodology. Furthermore, tribometric research on rubber-like materials confirms the need for dynamic data from humans and slipping. Unfortunately, this problem has been underestimated.

Consequently, we have developed the Fall Prevention Rig which is intended to allow the study of falls, while preventing contact between the human being and the environment in an uncontrolled manner. So far, some authors have developed a sort of support system in slip/fall study. In all cases, however, slipping behavior was produced by providing abnormally slippery surfaces. The rig at Texas Tech provides the capability of adjusting the speed of the rig to the speed of the subject. It can operate continuously, providing long exposures, for example, requiring the subject to walk around the track for periods of up to one or two hours. This exposure is intended to allow the use of surfaces with a coefficient of friction more normally met in practice.

Other studies which will focus on other environmental conditions such as the loading carrying condition, the perception of slipperiness study, and the dynamic friction measurement need to be done in the future. the biomechanical data collected in this study will be basis for further understanding in the future research.

Acknowledgements

This work was carried out with the support of the Center for Disease Control in U.S.A.

References

[1] Perkins, P.J., Measurement of Slip between the Shoe and Ground during Walking, American Society of Testing and Materials, Special Technical Publication 649, pp.71-87, 1978.

[2] Perkins, P.J., and Wilson, M.N., Current Work on Sole Slip Resistance, Ergonomics, 26-1, pp.193-196, 1983.

[3] Stevenson, M.G., Lioyd, D.G., Buntemgchit, Y., and Hoang, K., Measurement of Slip Resistance of Shoes on Floor Surfaces, The Center for Safety Science, The University of New South Wales, Australia, 1988.

[4] Strandberg, L., On accident Analysis and Slip Resistance Measurements, Ergonomics, 26-1, pp.11-32, 1983.

[5] Tisserand, M., Criteres d'Adherence des Semelles de Securite, Institut national de Recherche et de Securite, Nancy France, 1969.

[6] Tisserand, M., Progress in the Prevention of Falls Caused by Slipping, Ergonomics, 28-7, pp.1027-1042, 1985.