Journal of the Korean Institute of Industrial Engineers
Vol. 27, No. 2, pp. 197-202, June 2001.

미끄러져 넘어짐의 생체학적 연구에 있어서 부하이동이 끼치는 영향

명 노 해†

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Load Carrying Effect on the Biomechanical Parameters of Slips and Falls

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The biomechanical analysis of the load carrying effect on different floor surfaces has been conducted. Four different floor surfaces were prepared for ten subjects with each walking at a fixed velocity(1.33 m/sec) while carrying five different loads. The results showed that because of the significant interaction effect between floor slipperiness and the load carrying task, the load carrying effect should be analyzed according to different levels of the floor slipperiness, especially contaminant floors. On oily surfaces, slip distance(SD) and heel velocity (HV) increased whereas stride length(SL) decreased as load increased. In other words, significantly longer SD, faster HV, and no normal gait were found as load increased. As a result, a different protocol should be applied to measure floor slipperiness on oily floors as compared to dry surfaces for tribological approach.

Keywords : Slip distance, stride length, heel velocity, load carrying, gait pattern

1. Introduction

Biomechanical and tribological approaches have been studied to reduce the occupational injuries related with slips and falls and have remarkably contributed to uncover the human biomechanics for the accurate measure of dynamic coefficient of friction(DCOF) which has been used for the representation of the floor slipperiness.

Strandberg and Lanshammar(1981) mentioned that the vertical force was one of the particularly important variables that slip resistance meters should be reproduced from gait phases based on tribological and practical experience. To investigate how much the vertical force should be reproduced for DCOF measures, the biomechanical study of the load carrying task has been conducted. Since the biomechanical approach deals with the human subjects, the body weight has been simply considered as the vertical force. Therefore, the body weight changes during a slip have been also investigated. Strandberg and Lanshammar (1981) reported that 60 percent of the body weight was seen during a slip. Gröqvist *et al.*(1989), quoting Skiba *et al.*(1983), reported that vertical force when the slip motion starts varied between 35 to 90 percent of body weight.

Three important biomechanical parameters have been studied for human reactions to slips and falls related to the load carrying task. Slip distance has been studied to find the load carrying effect(Li, 1991) and found that slip distance was significant and increased with the extra load carried. Heel velocity has been also investigated with respect to different load carrying levels. Li(1991) found that heel velocity was significantly different under load carrying conditions. However, Redfern *et al.*(1991) found that the load carrying

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Received September 2000, accepted January 2001 after 2 revisions.

condition had only minor effects on the heel movement parameters and therefore was considered to be generally insignificant. Stride length, one of the most essential determinants in gait analysis(Ohmichi and Miyashita, 1983), has been also studied for the load carrying effect. Kinoshita(1985) found that stride length should be shortened as the load was increased so that a faster transfer of the body weight from one leg to the other could be accomplished. Martin and Nelson(1986) and Li(1991) concluded that stride length decreased while cadence increased with increased in load.

As a result, many researchers have studied the load carrying effects on slips and falls and found that important biomechanical parameters, such as heel velocity and vertical force, should be reproduced for the DCOF measures. To investigate the human reactions for the load carrying tasks related to slips and falls study, researchers found that the load carrying effect was significant to gait pattern(stride length) on oily floors(Li, 1991) but not significant on dry floors (Kinoshita, 1985). Even with this significant load carrying effect on oily floors, additional attention to vertical force levels in the tribological approach has not been taken into consideration for the measure of DCOF. In other words, body weight has not been applied to the vertical force to measure floor slipperiness in tribological approach. In addition, carrying an external load is a typical activity in normal life and industry so that the load carrying task should be considered in the biomechanical approach to investigate the effect of extra load to the human reaction on different floor slipperiness.

Therefore, this study was conducted to investigate the load carrying effect using typical methods on a wide range of floor slipperiness for both biomechanical and tribological approaches. The load carrying effect in a biomechanical approach is comparable to the vertical force effect on the DCOF tribological parameter, which was found to be significant but accounted for only small changes in DCOF (Redfern *et al.*, 1991). Another objective of this study was to investigate the contaminant effect related to the load carrying task because the contaminant effect was found to be significant for DCOF measures in the tribological approach.

2. Method

2.1 Subjects

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

2.2 Apparatus

Four different floor materials were chosen for the experiment : plywood, ceramic tile, vinyl tile and stainless steel plate. The dimensions of the simulated floor were 250 cm × 30 cm × 2.5 cm. Sixteen ceramic tiles(15 cm × 15 cm), eight vinyl tiles(30 cm × 30 cm), and a sheet of stainless steel plate were mounted on a piece of plywood. The simulated floors were mounted in a shallow pit, so that the floor surface height would be leveled with the laboratory floor and no trapping hazards would exist. To reduce the visual effect of floor materials, the color and contrast for all floor materials were similar.

A container(46 cm × 30 cm × 30 cm), which was made with 1.3 cm thick plywood and weighed 10 kg, was used for the carrying task. Lead bars were arranged at the center area of the plywood container to control the symmetric weight distribution. The container had 15.2 cm handles on both sides to make it easy to carry. In addition, a supporting strap was attached to both sides to protect the container from falling onto the subject.

For the collection of three-dimensional biomechanical data, the ExperVision motion analysis system was used with 60 Hz. In order to protect subjects from falling during the experiment, a fall arresting rig was used. The speed of the fall arresting rig was fixed at 1.33 m/sec. Whenever an imbalance is detected, the system immediately arrests the fall and discontinues its motion.

2.3 Experimental Design and Statistical Analysis

For the statistical analysis, the variance-component model for the repeated measures with factorial design was used with subjects as a random block term. With no significant main interaction effect, the Student-Newman-Keuls(SNK) multiple comparison test was performed to classify the main treatment levels. However, a contrast with Fisher's least significant difference(LSD) was used if there were a significant main interaction effect. For this study, three dependent variables were chosen: slip distance, stride length, and heel velocity. Two independent variables were DCOF and load carrying levels.

Four different DCOF floor materials were chosen to represent a wide range of floor slipperiness. A programmable slip resistance tester was used to measure

DCOF with a heel velocity of 15 cm/sec and a vertical force of 9 kg. Four selected floors were : oily vinyl tile(DCOF = 0.11) ; dry stainless steel(DCOF = 0.27) ; oily plywood(DCOF = 0.43) ; and dry ceramic tile (DCOF = 0.57).

Five different load carrying levels were chosen based on the percentage of body weight and fixed load weight methods. For the percentage of body weight method, 40 % of body weight was the recommended maximum carrying weight by Cathcart *et al.*(1923) so that 20 and 40 % of body weights were chosen. For the fixed load method, 18 and 24 kg were chosen because 18 kg is typically found as a mass handled in grocery stores and in the industrial environment and 24 kg was recommended as the maximum acceptable weight of carry(MAWC) for 90 % of the industrial male workers by Snook (1978). No load was included as the controlling load carrying level. Five levels were (1) no external load(NO LOAD), (2) loads of 20 percent(20 % BW) and (3) 40 percent of the body weight(40 % BW), and (4) 18 Kg(18 KG) and (5) 24 Kg(24KG) loads carried in a container held against the body.

2.4 Procedure

The procedure for this study followed the previous study(Myung and Smith, 1997) and the details are as follows. To analyze the subject's movement, retroreflectors were attached to the anatomically significant body positions defined by Winter(1992) : heel, toe, ankle, knee, and hip of the subject's left side. All subjects wore the same shoes(available in a variety of sizes) with a PVC sole to have consistent frictional values. Prior to these experiments, each subject was given an opportunity to walk around the laboratory to familiarize himself with the task at the pace of his normal walking speed. The walkway track was circular, with a circumference of approximately 25 m. The simulated floors were placed in a 2.5 m straight section of the walking track.

Subjects were then asked to walk across the floor samples while wearing a harness attached to the fall arresting rig. Data collection was started right after subjects crossed the photo cells and lasted for 3 seconds. Right before the left side photo cell in subject's 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.

Ten combinations(5 load levels × 2 replications) of the load carrying conditions were totally randomized within each floor surface. Subjects were allowed to walk freely without any arm movement restrictions with no external load. Each subject had 40(4 floors × 5 load levels × 2 replications) trials of walking for this study. The floor samples were arranged so that each subject walked on a floor surface with the left foot on the left surface and the right foot on the right surface. 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 instructed to keep their eyes on the front wall and to try to maintain the walking speed that they practiced.

3. Results and Discussion

The ANOVA test for the full model was first performed to find the insignificant random interaction effect and then the ANOVA test for the reduced model was again performed after removing the insignificant random interaction terms. The results are shown in <table 1>. No further investigation for the SUBJ-related random interaction terms was made because the analysis of the SUBJ-related random terms was not great concern in this research. The load carrying effect was represented by LOAD in <table 1>.

For the fixed term, the main interaction term (DCOF *LOAD) was first investigated because the interpretation of the main effect tests depends on the significance of the main interaction effect. Since the DCOF *LOAD interaction effect for slip distance was found to be significant with p-value = 0.0178, the contrast was used and the results of Fisher's LSD groups are shown in <table 2>. No significant slip distance (SD) mean differences were found for ceramic and steel at every load level. For plywood, two statistically significantly different groups were found. SD for carrying a 40 % BW was significantly different from SD for carrying a 20 % BW and NO LOAD. For vinyl, three statistically significant groups were classified for

Table 1. ANOVA summary for slip distance, stride length and heel velocity with p-values

SOURCES	Slip Distance	Stride Length	Heel Velocity
DCOF	0.0001	0.0001	0.0001
LOAD	0.0001	0.0001	0.0002
DCOF*LOAD	0.0178	0.3735	0.1334
SUBJ	0.0599	0.0001	0.0851
SUBJ*DCOF	0.0001	0.0001	0.0001
SUBJ*LOAD	—	—	0.3042
SUBJ*DCOF*LOAD	—	0.0009	—

Table 2. Least significant difference(LSD) groups for SD with LOAD (unit: cm)

LOAD	CERAMIC		STEEL		PLYWOOD		VINYL	
	MEAN	LSD	MEAN	LSD	MEAN	LSD	MEAN	LSD
NO LOAD	0.27	A	0.28	A	3.14	A	4.99	A
20 % BW	0.27	A	0.34	A	3.22	A	7.09	B
18 KG	0.41	A	0.42	A	4.24	AB	7.99	B
24 KG	0.36	A	0.41	A	4.35	AB	8.59	B
40 % BW	0.60	A	0.62	A	5.64	B	11.54	C

the load carrying effect. Carrying the load of 40 % BW created the significantly longer SD than any other load levels. No significant difference was found among 20 % BW, 18 KG, and 24 KG. NO LOAD was found to create the shortest SD and was significantly different from other load carrying levels.

As a result, the load carrying effect should be interpreted according to different floor slipperiness because of the significant interaction effect. The least slippery floor(ceramic) was not found to be significant for the load carrying effect. The first and third most slippery floors(vinyl and plywood) based on DCOF measure were found to be significant for the load carrying effect. The inconsistency of the load carrying effect to SD was found with steel.

For the contaminant effect, the dry versus oily contrast was calculated and the results are shown in <table 3>. No significant difference was found with any combinations of load levels at dry surfaces. However, three significantly different groups were classified for oily surfaces. The heaviest load level, 40 % BW, was found to be significantly different from the other load levels. No difference was found between 20 % BW and NO LOAD as well as among 24 KG, 18 KG, and 20 % BW. NO LOAD was also significantly different from 18KG, 24KG and 40 % BW.

According to the load carrying effect, Snook and Ciriello(1991) tabularized the maximum acceptable weight of carrying(MAWC) based on pshychophysical approach. The MAWC, if a job requires a carry at knuckle height(79 cm) for 8.5 meters, is 24, 40, and 56 Kg for 90 %, 50 %, and 10 % of male industrial population, respectively. Compared to the load carrying effect on SD(<table 2> and <table 3>), SDs for dry floors are well in the range of the recommendations of Snook and Ciriello's but SDs for oily floors are classified "midi slip", which subjects regained balance,

Table 3. Least significant difference (LSD) groups for the 'dry versus oily' contrast to SD with LOAD (unit : cm)

LOAD	DRY		OILY	
	MEAN	LSD	MEAN	LSD
NO LOAD	0.27	A	4.06	A
20 % BW	0.31	A	5.16	AB
18 KG	0.41	A	6.11	B
24 KG	0.38	A	6.47	B
40 % BW	0.61	A	8.61	C

without apparent gait pattern disturbance(Strandberg, 1983). For carrying 40 % of body weight (about 30 Kg), subjects demonstrated large compensatory swing-leg and arm motions, 'maxi-slip'. In other words, the MAWC should be applied strictly on dry surfaces and should be reconsidered on oily floors.

Stride length (SL) was also used to find the load carrying effect. Since the main interaction effect was not significant to SL with p-value = 0.3735(<table 1>), the SNK multiple comparison test was performed to differentiate main treatment levels. According to the SNK multiple comparison test, four significantly different groups were classified. In group A, subjects had the longest SL(147 cm) when they walked without the load. There was no significant difference between 20 % BW(140.9 cm) and 18 KG(139.4 cm) in group B. The second heaviest load, 24 KG(137.3 cm) in group C, created the second shortest SL while the heaviest load, 40 % BW(134.1 cm) in group D, had the shortest SL. As a result, subjects adjusted their SL by decreasing it as the load increased. Assuming NO LOAD as the normal gait, subjects decreased SL by 13 cm for 40 % BW, which is therefore considered an abnormally short gait. Based with NO LOAD on ceramic and steel, the normal gait(stride length) was measured from 144 cm to 147 cm in this study. For contaminant effect, oily surfaces produced significantly longer SL (141.2 cm) than SL(136.3 cm) on oily surfaces.

Heel velocity (HV) was used to find the load carrying effect, too. The full and reduced models were investigated and the DCOF*LOAD interaction effect was marginally significant with p-value = 0.1334 (<table 1>). Since the rule of thumb of assuming no interaction effect was to have greater than 0.25 p-value, the contrast was used to investigate the interaction effect in detail and the results of the contrast analysis is shown in <table 4>. No load effect was expected from ceramic and steel because no contrast was found significant. The load carrying

Table 4. Least significant difference(LSD) groups for HV with LOAD (unit: cm/sec)

LOAD	CERAMIC		STEEL		PLYWOOD		VINYL	
	MEAN	LSD	MEAN	LSD	MEAN	LSD	MEAN	LSD
NO LOAD	10.24	A	14.15	A	66.81	A	93.50	A
20 % BW	13.69	A	12.11	A	77.38	A	113.77	B
18 KG	22.50	A	23.71	A	77.46	A	144.66	B
24 KG	16.71	A	34.49	A	94.82	AB	126.28	B
40 % BW	24.20	A	33.10	A	121.31	B	175.00	C

levels of plywood were classified into two significantly different groups while vinyl had three. For vinyl, 40 % BW had the significantly faster HV than at other load carrying levels. No difference was found among 24 KG, 18 KG, and 20 % BW. NO LOAD had significantly slower HV compared to other load carrying levels. For plywood, the HV for group A was significantly slower than the HV for group B. As mentioned before, no significant difference was found in the same group even though there was the mean difference. The 'dry versus oily' contrast was again used to investigate the contaminant effect for the load carrying levels with HV. As with SD, no significant difference was also found with dry surfaces while three significantly different groups were also classified and the significant groups were the same as the groups for SD(<table 5>). In other words, dry surface had a minor effect on the load carrying effect as mentioned by Redfern *et al.*(1991) but oily floors were found to be à significant impact on the load carrying effect.

As a result, SD and HV increased as load increased but SL decreased as load increased. The reason for the increasing trend of HV might be the cadence change because of reducing SL. To keep the same walking velocity, subjects increased cadence with shorter SL. To have increased cadence, the foot should move faster for the very next step. By moving a foot faster, the faster HV would be expected until right before the heel contacted the floor surface. This faster HV before the heel contacted the floor surface affected the fast landing of the leading foot for the compensation of the body instability due to oily floors.

Table 5. Least significant difference (LSD) groups for the 'dry versus oily' contrast to HV with LOAD (unit: cm/sec)

LOAD	DRY		OILY	
	MEAN	LSD	MEAN	LSD
NO LOAD	12.19	A	80.19	A
20%BW	12.90	A	95.57	AB
18KG	23.10	A	110.06	B
24KG	25.60	A	110.55	B
40%BW	28.65	A	148.16	C

In addition, due to the significant interface effect, the load carrying effect also needed separate analyses according to floor slipperiness, dry and oily surfaces. Contaminant effects overpowered the floor slipperiness effects for the load carrying levels. No load carrying effect was found for dry floors whereas significant load carrying effects were found for oily floors. At least 40 % BW should be applied to find the load carrying effect clearly with oily floors because no difference was found until 24 KG between plywood and vinyl(<table 4>). Therefore, the realistic vertical force range should be at least 40 % BW to measure proper DCOF for the tribological approach, which confirmed the results of vertical force levels during a slip by Strandberg and Lanshammar(1981) and Skiba *et al.*(1983).

4. Conclusions

The biomechanical analysis of the load carrying effect has been conducted with three biomechanical parameters (slip distance, stride length, and heel velocity) compared to the tribological DCOF measures. The conclusions for this study are as follows :

(1) Because of the significant interaction effect between floor slipperiness and the load carrying task, the load carrying effect should be analyzed according to different levels of the floor slipperiness, especially contaminant floors. The load carrying effect on SD showed that the maximum acceptable weight of carrying should be strictly applied to dry floors and should be reconsidered on oily floors because significantly longer(dangerous) SD were found than dry floors. The normal gait was found to be maintained only on dry floors. HV on oily floors were found to be a significant impact on the load carrying but a minor effect was found on dry surfaces as found by Redfern *et al.*(1991).

(2) Concerning load carrying effects, slip distance (SD) and heel velocity(HV) increased whereas SL decreased as load increased. The load carrying effect was found to be highly significant for all independent

variables. However, in previous tribological studies (Redfern *et al*., 1991; Redfern and Bidanda, 1993), the vertical force had only a minor effect on DCOF measures. This is because the vertical force ranged up to only 13.5 Kg for the previous study. The tribological approach has been too conservative to find a significant vertical force effect. To have the realistic vertical force range for DCOF measures in tribological approach, at least 40 % of body weight should be applied.

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