行政院國家科學委員會專題研究計畫 成果報告

鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響(第3年)

研究成果報告(完整版)

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行政院國家科學委員會補助專題研究計畫成果報告

鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響

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目　錄

摘　要

人工物料處理是工業界造成肌肉骨骼傷害的主要原因之一。本研究為三年期研究計畫，第一年在三種頻率(1,2,3 次/分鐘)三種鞋材下執行複合人工物料搬運作業；第二年在四種抬舉放下高度組合(F-F, FK, K-F, K-K)三種鞋材下下執行複合人工物料搬運作業；第三年在三種攜行距離(8.5, 3, 1m) 下執行一項複合人工物料搬運作業。受測者下進行抬起、攜行、放下、再走回原點的作業決定其最大可接受重量。之後，受測者再以相同的條件作業十分鐘，研究人員收集了 PSOS、心跳率、VO_2、與全身體力負荷的 RPE 值。實驗結果顯示頻率、抬舉放下高度及攜行距離對最大可接受重量、心跳率、與 VO_2 都有顯著的影響($p<0.05$)，對 RPE 的影響則不顯著。鞋材在實驗中僅對 PSOS 有顯著的影響。

關鍵詞： 人工物料處理、頻率、VO_2、RPE、心跳率

Abstract

Manual materials handling is one of the major contributors to musculoskkelatal disorders in industry. This project was a three-year project. In the first year, a combined manual materials handling tasks experiment was performed under three frequency (1, 2, 3 per minute) and three footwear conditions. In the second year, a combined manual materials handling tasks experiment was performed under four lifting & lowering ranges (F-F, F-K, K-F, K-K) and three footwear conditions. In the third year, a combined manual materials handling tasks experiment was performed under three carrying distance (1, 3, or 8.5 m) and three footwear conditions. The maximum acceptable weight of handling, including lifting, carrying for, lowering, and walking back to the origin was determined. The subject then performed the same tasks for 10 minutes handling the maximum acceptable weight he has selected. The PSOS, VO_2, heart rate, and rating of perceived exertion for whole body strain were measured. The results showed that the effects of frequency, lifting & lowering range, and carrying distance on the maximum acceptable weights of handling, heart rate, and VO_2 were all statistically significant ($p<0.05$). The effects of frequency on RPE was, however, not significant. The effects of footwear was significant only for the PSOS.

Keywords: manual material handling, carrying distance, VO_2, RPE, heart rate

1. Introduction

The MMH tasks are very common on construction sites and on other types of workplaces [1,2,3], and are one of the major contributors for musculoskeletal symptoms for workers. Workers manually handle materials of all kinds [4]. The MMH tasks at construction sites normally have a high degree of variability, both in duration and content [1, 5, 6]. This complexity in construction work makes ergonomics interventions much more complicated as compared to those in the manufacturing and service sectors.

One of the most widely accepted approaches in designing MMH tasks is to design or modify a job so as not to exceed the capabilities of the materials handlers [7-11]. Physiological measures are one of the scientific means to evaluate the physical burdens and capabilities of workers in MMH tasks under various job conditions. Physiological parameters such as the oxygen consumption and heart rate may be used reliably to indicate physiological burden of the worker. In the physiological approach, a job is usually divided into simple individual tasks, and the physiological cost of the job is assumed to be the sum of the energy expenditures of these individual tasks. Many researchers have developed regression equations to predict oxygen consumption using personal, task, and workplace variables based on this assumption. The most comprehensive and flexible predictive equations in the MMH tasks were developed in 1978 by Garg et al [12].

Subjective measures may be used to quantify the physical strain caused by physical activities. The ratings of perceived exertion (RPE) developed by Borg [13] has been one the most commonly used subjective measures in assessing the whole body and segmental strain. The RPE is constructed so that the ratings, 6 to 20, are linearly related to the heart rate expected for that level of exertion. As indicated by Hutchinson and Tenenbaum [14], a single measure of RPE is insufficient to capture the whole range of perceptual sensations that people experience when exercising or being physically active. There are numerous examples of using the RPE as supplementary measures in addition to some objective measures in studying the MMH tasks [15-18] and other physical phenomena and activities [19. 20]. Subjective rating may be used to quantify the perception of instability and perceived floor slipperiness of a person working and walking on a less slip-resistant surface. The Perceived Sense of Slipperiness developed by Chiou et al. [21]. The PSOS was determined by adding the four ratings in Table 1. A high PSOS score implies a high subjective perception of slip and loss of balance during the MMH tasks.

Table 1.1 Perceived Sense of Slip (PSOS) rating scale (Chiou et al., 2000)

1) How much did you feel yourself slip (i.e. loss of foot traction)?

a little		Some		a lot
0	0.5	1	1.5	2

2) Did you have any difficulty in maintaining balance (how much did you or your muscles compensate for your movement)?

a little		Some		a lot
0	0.5	1	1.5	2

3）Did you feel at any time that you would slip?

a little		Some		a lot
0	0.5	1	1.5	2

4）What would you say was the overall difficulty of this task?

a little		Some		a lot
0	0.5	1	1.5	2

This project was the final part of a three-year project. The focus of the study was to address the MMH tasks under different footwear-floor friction conditions and to test the job design parameters. In the first year, we conducted experiment testing the effects of footwear materials and frequency on the MAWH and both physiological and subjective responses of the subjects. In the second year, the lifting and lowering range was tested in addition to the footwear conditions. The objective of the study was to determine the maximum acceptable weight of handling when performing combined manual materials handling tasks and to determine the physiological and perceptual responses of the subjects in performing such a task.

2. Experiment 1

2.1 Methods

Twelve male subjects, free from any cardiovascular and neuro-musculoskeletal disorders were recruited for this study. Their mean (±std) age, height, and body weight were 21.8 (±2.4) years, 168.8 (±4.3) cm, and 64.2 (±14.2) Kg, respectively. All participants signed an informed consent, and were compensated financially for their participation in the study. The temperature and humidity in the laboratory was 21~23°C and 47~64%, respectively.

2.1.1 Manual Materials Handling Tasks

A plastic container with handles commonly used in local industry was used. Sand bags of 0.1, 0.2, 0.5, and 1 kg were prepared as the materials to be handled. The subject was required to lift the container with a certain amount of weight, from a height of 75 cm, to his elbow height and carry it for 3 m, then lower the container onto a table of the same height. The subject then walked back 3 m, empty-handed, to the original starting position. In other words, one task included a lifting, carrying for 3 m, lowering, and walking empty-handed for 3 m. The frequency of this task was either 1, 2, or 3 per minute. In addition to the frequency, shoes of three different sole materials were used: cloth, PVC, and rubber. The coefficient of friction (COF) between the shoe sole and floor was measured using the Brungraber Mark II slipmeter. Friction measurement procedure followed the ASTM [22] requirements. Neolite footwear pads with a dimension of 7.6×7.4 cm were used. The density and shore A hardness of this material were 1.28 g/cm^3 and 90, respectively. The walking speeds of the subjects were not controlled. However, they were required to complete two tasks each minute and were instructed to maintain consistent working and walking pace during the experiment.

2.1.2 Procedure

All subjects were instructed to refrain from heavy physical activity before attending the experiment. Before the experiment, the resting heart rate of the subject was measured and the researcher explained the purposes and procedure of the study to the subject. Each session started with the determination of the maximum acceptable weight of handling (MAWH). The MAWH was the terminology used to indicate the maximum acceptable weight that a subject could handle under the lifting, carrying, lowering, and walking back to the origin. This terminology has been used in the previous study [18]. The subject started to handle an initial weight following the described protocol in the previous section after a 5-minute break. The initial weight was in the range of 6 to 12 kg. In the experiment, an initial weight was randomly assigned using a weight either the lower limit or the upper limit. Approximately half of the trials started at a weight near the lower limit while the other half started at a weight near the upper limit.

The subject took a ten minutes break after he determined his MAWH. He, then, put on a K4b2® metabolic measurement unit and a Polar® heart rate monitor. The subject started a same material handling tasks with a load of his MAWH for ten minutes. His VO_2 and heart rate during this period were recorded. The means of the last five minutes were used for statistical analysis. After the experiment, the subject reported his perceived physical exertion for the MMH task been performed using a Borg's Ratings of Perceived Exertion Scale [13] ranging from 6 to 20.

2.1.3 Experiment design & data analysis

The experiment was conducted using a two-factor completely randomized design. In addition to descriptive statistics, analysis of variance (ANOVA) and descriptive statistics were performed. Tukey's honest significant difference (HSD) tests were conducted if a factor was found significant in the ANOVA. The statistical analyses were performed using the SPSS® 14.0 computer software.

2.2 Results

Table 2.1 shows the ANOVA results for all the dependent variables in experiment 1. Frequency was a significant factor affecting MAWH (p<0.0001), VO2 (p<0.0001), and HR (p<0.001) but not for RPE and PSOS. Footwear material was a significant factor affecting the PSOS (p<0.0001).

表 2.1 ANOVATable for experiment 1

		SS	df	MS	F	*p*-value
MAWH	frequency	59.69	2	29.85	13.90	0.000
	footwear	1.55	2	0.77	0.36	0.699
	error	212.51	99	2.15		
VO2	frequency	976923.45	2	488461.72	25.27	0.000
	footwear	22531.72	2	11265.86	0.58	0.56
	error	1913921.92	99	19332.55		
HR	frequency	2204.89	2	1102.45	6.93	0.002
	footwear	218.92	2	109.46	0.69	0.505
	error	15744.33	99	159.03		
RPE	frequency	4.52	2	2.26	1.19	0.308
	footwear	2.24	2	1.12	0.59	0.555
	error	187.42	99	1.89		
PSOS	frequency	0.60	2	0.30	0.26	0.773
	footwear	21.68	2	10.84	9.35	0.000
	error	114.79	99	1.16		

Table 2.2 shows the results of Tukey's HSD test results for MAWH. The MAWH at once per minute (9.2±1.58 kg) was significantly (p<0.05) higher than those of 2 (8.0±1.31 kg) and 3 (7.4 ± 1.46 kg) per minute.

Table 2.2 Tukey's HSD results for MAWH

Frequency (per minute)	mean	Tukey's group
3	7.4	A
2	8.0	A
1	9.2	B

$p<0.05$

Table 2.3 shows the results of Tukey's HSD test results for VO_2. The VO_2 at 3 per minute (679.37±172.55 ml/min) was significantly ($p<0.05$) higher than those of 2 (578.51±129.35 ml/min) and 1 (447.07±95.41 ml/min) per minute. The VO_2 at 2 per minute was significantly ($p<0.05$) higher than that of 1 per minute.

Table 2.3 Tukey's HSD results for VO_2

Frequency (per minute)	mean	Tukey's group
1	447.1	A
2	578.5	B
3	679.4	C

$p<0.05$

Table 2.4 shows the results of Tukey's HSD test results for HR. The HR at 3 per minute (99.57 ±13.44 bpm) was significantly ($p<0.05$) higher than those of 1 (88.51±11.41 bpm) per minute. The HR at 2 per minute was not significantly different from those of the other two frequencies.

Table 2.4 Tukey's HSD results for HR

Frequency (per minute)	mean	Tukey's group
1	88.5	A
2	93.7	AB
3	99.6	B

$p <0.05$

The Tukey's HSD results for PSOS testing against footwear shows that the cloth-soled footwear had a significant higher PSOS rating than those of the other two footwear materials.

3. Experiment 2

3.1 Methods

Twelve male subjects, free from any cardiovascular and neuro-musculoskeletal disorders were recruited for this study. Their mean (±std) age, height, and body weight were 21.0 (±0.7) years, 172.8 (±6.3) cm, and 66.3 (±11.1) Kg, respectively. All participants signed an informed consent, and were compensated financially for their participation in the study. The temperature and humidity in the laboratory was 21~23°C and 47~64%, respectively.

3.1.1Manual Materials Handling Tasks

The same plastic container and sand bags used in section 2.2 was used. The subject was also required to lift the container with a certain amount of weight and carry it for 3 m, then lower the container onto a height. The subject then walked back 3 m, empty-handed, to the original starting position. In other words, one task included a lifting, carrying for 3 m, lowering, and walking empty-handed for 3 m. The frequency of this task was 2 per minute. The lifting and lowering range included lifting from floor and lowering onto floor (F-F), lifting from floor and lowering onto knuckle height (F-K), lifting from knuckle height and lowering onto floor (K-F), and lifting from knuckle height and lowering onto the knuckle height (K-K). In addition to the lifting & lowering range, the three types of same shoes were used. The walking speeds of the subjects were not controlled. However, they were required to complete two tasks each minute and were instructed to maintain consistent working and walking pace during the experiment.

3.1.2 Procedure

Similar procedure as in section 2.3 was adopted.

3.1.3 Experiment design & data analysis

The experiment was conducted using a two-factor completely randomized design. In addition to descriptive statistics, analysis of variance (ANOVA) and descriptive statistics were performed. Tukey's honest significant difference (HSD) tests were conducted if a factor was found significant in the ANOVA. The statistical analyses were performed using the SPSS® 14.0 computer software.

3.2 Results

Table 3.1 shows the ANOVA results for experiment 2. It was found that lifting & lowering range was a significant factor affecting MAWH (p<0.0001), VO_2 (p<0.0001), and HR (p<0.05). Footwear was a significant factor affecting PSOS (p<0.0001).

Table 3.1 ANOVA table for dependent variables

		SS	Df	MS	*p*-value
MAWH	Footwear	6.27	2	3.13	0.218
	Lifting &lowering range	40.91	3	13.64	0.000
	Error	268.09	132	2.03	
VO_2	Footwear	8158.41	2	4079.21	0.798
	Lifting &lowering range	446764.61	3	148921.54	0.000
	Error	2383223.38	132	18054.72	
HR	Footwear	60.90	2	30.45	0.729
	Lifting &lowering range	913.29	3	304.41	0.027
	Error	12674.37	132	96.02	
RPE	Footwear	1.93	2	0.97	0.525
	Lifting &lowering range	0.94	3	0.32	0.889
	Error	197.00	132	1.49	
PSOS	Footwear	35.28	2	17.64	0.000
	Lifting &lowering range	1.01	3	0.34	0.887
	error	207.46	132	1.57	

Table 3.2 shows the Tukey's HSD results for MAWH. The MAWH for M-M (9.02±1.42 kg) was significantly (p<0.05) higher than that of F-F (7.52±1.38kg). The MAWH for both the F-M (8.35±1.41 kg) and M-F (8.20±1.40 kg) were not significantly different from both the MAWH of F-F and M-M.

Table 3.2 Tukey's HSD results for MAWH

Lifting & lowering range	mean	Tukey's group
F-F	7.5	A
M-F	8.2	AB
F-M	8.4	AB
M-M	9.0	B

p<0.05

Table 3.3 shows the Tukey's HSD results for VO_2. The VO_2 for F-F (721.53±160.47 ml/min) was significantly (p<0.05) higher than those of M-F (605.21±107.49 ml/min) and M-M (573.49± 121.16 ml/min). The MAWH for both the F-M (8.35±1.41 kg) and M-F (8.20±1.40 kg) were not significantly different from both the MAWH of F-F and M-M.

Table 3.3 Tukey's HSD results for VO_2

Lifting & lowering range	mean	Tukey's group
M-M	573.5	A
M-F	605.2	A
F-M	652.0	AB
F-F	721.5	B

p<0.05

Table 3.3 shows the Tukey's HSD results for heart rate. The HR for F-F (721.53±160.47 ml/min) was significantly (p<0.05) higher than those of M-F (100.93±9.76 bpm) was significantly higher than that of M-M (94.36±8.70 bpm). The MAWH for both the F-M (98.59±10.38 bpm) and M-F (95.90±9.53 bpm) were not significantly different from both the MAWH of F-F and M-M.

Table 3.4 Tukey's HSD results for HR

Lifting & lowering range	mean	Tukey's group
M-M	94.4	A
M-F	95.9	AB
F-M	98.6	AB
F-F	100.9	B

p<0.05

The Tukey's HSD results for PSOS testing against footwear shows that the cloth-soled (2.8) footwear had a significant higher PSOS rating than those of the other two footwear materials (1.8 and 1.7).

The Pearson's and Spearman's correlation coefficients between the MAWH and RPE were -0.30 (p<0.01) and -0.376 (p<0.01), respectively. The Pearson's and Spearman's correlation coefficients between the PSOS and RPE were 0.26 (p<0.01) and 0.31 (p <0.01), respectively.

4. Experiment 3

4.1 Methods

Twelve male college students, free from any neuro-musculoskeletal disorders were recruited for this study. Their mean (±std) age, height, body weight, resting oxygen uptake, resting and heart rate were: 23.4 (±1.7) years, 173.8 (±4.4) cm, 65.4 (±17.2) Kg, 0.282 (±0.068) L/min, and 86.0 (±9.5) beats/min, respectively. All participants signed an informed consent, and were compensated financially for their participation in the study. The mean temperature and humidity in the laboratory was 22°C and 65%, respectively.

4.1.1 Manual Materials Handling Tasks

The same plastic container used previously was used. The subject was required to lift the container with a certain amount of weight, from a height of 75 cm, to his elbow height and carry it for a distance, then lower the container onto a table of the same height. The subject then walked back for the same distance, empty-handed, to the original starting position. Three carrying distances were tested: 1 m, 3 m, and 8.5 m. The frequency of this task was either 2 per minute.

The walking speeds of the subjects were not controlled. However, they were instructed to maintain consistent working and walking pace during the experiment.

4.1.2 Procedure

Similar procedure as in the previous sections was adopted.

4.1.3 Experiment design & data analysis

The experiment was conducted using a two-factor completely randomized design. In addition to descriptive statistics, analysis of variance (ANOVA) and descriptive statistics were performed. Tukey's honest significant difference (HSD) tests were conducted if a factor was found significant in the ANOVA. The statistical analyses were performed using the SPSS® 14.0 computer software.

4.2 Results

Table 4.1 shows the ANOVA results on MAWH. The effects of the footwear on the MAWH did not reach the 0.05 statistical significance level. The effects of distance was significant at $p<0.0001$.

Table 4.1 ANOVA results for MAWH

	SS	df	MS	*p*-value
Footwear	2.99	2	1.49	0.364
Distance	63.38	2	31.69	0.000
Error	144.70	99	1.46	

Tukey's HSD tests results indicated that the MAWH at 1 m carrying distance (8.8 kg) was significantly ($p<0.05$) higher than those of 3m (8.1 kg) and 8.5m (6.9 kg). The MAWH for the 3m distance was significantly ($p<0.05$) higher than that of the 8.5 m.

The ANOVA results showed that both footwear ($p<0.0001$) and carrying distance ($p<0.01$) were significant affecting the PSOS (see Table 4.2). For the VO_2, the effects of distance was significant ($p<0.0001$) but the effects of footwear was not significant (see Table 4.3). For the heart rate, the effects of distance was also significant ($p<0.0001$) but the effects of footwear was not significant (see Table 4.4). Both the effects of footwear and carrying distance on the RPE were not significant.

Table 4.2 ANOVA results for PSOS

	SS	df	MS	*p*-value
Footwear	88	2	43.89	0.000
Distance	16	2	8.16	0.006
Error	150	99	1.52	

Table 4.3 ANOVA results for VO_2,

	SS	df	MS	*p*-value
Footwear	4531	2	2266	0.903
Distance	1895127	2	947564	0.000
Error	2191736	99	22139	

Table 4.4 ANOVA results for heart rate

	SS	df	MS	p-value
Footwear	5.73	2	2.87	0.969
Distance	1362.09	2	681.05	0.001
Error	9136.80	99	92.29	

For footwear, the Turkey's HSD test results showed that the PSOS of the cloth-soled shoes (3.65) were significantly (p<0.05) higher than those of the PVC (1.86) and rubber (1.84). The difference between the PVC and rubber-soled shoes was not significant. For the carrying distance, the Turkey's HSD test results showed that the PSOS of the 8.5 m carrying distance (2.92) was significantly higher than that of 1 m (2.0). The PSOS of the 3 m carrying distance was not significantly different from both of the 1 m and 8.5 m conditions.

The Turkey's HSD test results showed that the VO_2 for the 8.5 m carrying distance (821.8 ml) was significantly (p<0.05) higher than those of the 3 m (594.8 ml) and 1 m (507.6 ml) conditions. For the heart rate, the values in the 8.5 carrying distance condition (100.9 bpm) was significantly (p<0.05) higher than those of the 3 m (94.4 bpm) and 1 m (92.6 bpm) conditions. The difference between the 3 m and 1 m conditions was not statistically significant.

The Pearson's (r) and Spearman's (ρ) correlation coefficients between the dependent variables were calculated. The correlation coefficients between the PSOS and VO_2 were positive and was significant at p<0.05 with r=0.32 and ρ=0.24, respectively. The correlation coefficients between the heart rate and VO_2 were also positive and was significant at p<0.01 with r=0.35 and ρ=0.28, respectively. The correlation coefficients between the MAWH and heart rate were positive and was significant at p<0.01 with r=0.28 and ρ=0.27, respectively. The correlation coefficients between the RPE and MAWH were positive and was significant at p<0.01 with r=0.35 and ρ=0.32, respectively. The Spearman's correlation coefficients between the MAWH and VO_2 were 0.17 (p<0.05).

5. Discussion

The results showed that the frequency of three per minute had significantly higher MAWH than those of the other two frequencies. This was not unexpected as higher frequency required higher metabolic energy and this would result in a lower weigh could be handled by the subject. The results among VO_2, and heart rate experimental conditions were consistent with the findings in the literature [23-29].

The results of the study indicated that footwear did not affect the MAWH, VO2, heart rate, and RPE significantly. Lifting and lowering height, however, was a significant factor affecting the MAWH, VO2, and heart rate. Lifting from the floor and lowering onto the floor was the most stressful condition among all lifting and lowering conditions. This was consistent with the finding in the literature [23-25] that either squatting or bending toward floor level to reach the weight and lift it resulted in high stress on the physiological system which may be monitored from the physiological measures such as VO2 and heart rate.

The results showed that the carrying distance of 8.5 m had significantly higher MAWH than those of the other two distances and the 3 m distance had higher MAWH than that of 1m. This was not unexpected as longer walking distance required higher metabolic energy and physical efforts and would result in a lower weigh could be handled by the subject.

One of our hypotheses was that the shoe soles possessing different slip-resistance affect the MAWH as extra efforts were required to maintain bodily balance when the friction was inadequate. This hypothesis was not supported by our data. The possible reason may be that the difference between the frictions among the shoe soles selected was not different enough so as to generate different results. Future research may be required to test more footwear materials so as to realize whether such a hypothesis would be supported in a more general footwear condition.

The overall mean RPE was 12.78, which corresponded to a level between “light” to “somewhat hard.” This RPE level was slightly lower than that (13) in one of our previous studies [18]. The college students in the current study carried 6.9 to 8.8 Kg which was lower than those in Li et al. [18] where their subjects handled weights ranged 7.8 to 10.7 Kg. The subjects in the former seemed to perceive a slightly lower whole body strain than the one in the current study. The college students in our study seemed to perceive their whole body strain slightly differently than the previous study [18].

The VO_2 results in the current study indicated that the energy expenditure of the subjects handling their MAWH was significantly affected by the carrying distance. This was reasonable. The implication was that load carrying should be performed using a cart instead of carrying manually. Load carrying should be minimized so as to reduce the physical burden of the workers.

There were limitations to this study. First of all, the results of the study should be taken as indicative because of the relative small sample size. Secondly, the walking velocities were not controlled. Variations of walking velocity might exist among the tasks performed in each session which might affect the results of the study.

References

[1] Lee, C.L., Lee, Y.H., Huang, J.L., Chen, C.Y., 2003. The study of workers' musculoskeletal disorders in building construction sites. Institute of Occupational Safety and Health Journal 11, 227-236 (in Chinese).
[2] Li, K.W., 2002. Ergonomic design and evaluation of wire-tying hand tools. International Journal of Industrial Ergonomics 30, 149-161.
[3]Wu, S.P., Chiu, C.P. 2007, Ergonomics Study of Musculoskeletal Injuries in the Hotel Housekeeping Worker, Journal of Occupational Safety and Health 15: 75-86.
[4] Li, K.W., Lee, C.L., 1999. Postural analysis of four jobs on two construction sites: an experience of using the OWAS method in Taiwan. Journal of Occupational Health 41, 183-190.
[5] Punnett, L., Paquet, V., 1996. Ergonomic exposures to construction carpenters and carpentry laborers in tunnel construction, In: Mital, A., et al., Advances in Occupational Ergonomics and Safety I, Proceedings of the XIth International Occupational Ergonomics and Safety Conference. IOS Press, Amsterdam, 99-104.
[6] Mirka, G.A., Kelaher, D.P., Nay, D.T., 2000. Continuous assessment of back stress (CABS): a new method to quantify low-back stress in jobs with variable biomechanical demands. Human Factors 42(2), 209-225.
[7] Snook, S.H., 1978. The design of manual handling tasks. Ergonomics 21, 963-985.
[8] Snook, S.H., 1985. Psychophysical considerations in permissible loads. Ergonomics 28, 327-330.
[9] Waters, T.R., Putz-Anderson, V, Garg, A., Fine, L., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36(7), 749-776.
[10]Ciriello, V.M., Snook, S.H., 1999. Survey of Manual Handling Tasks. International Journal of Industrial Ergonomics 23, 149-156.
[11]Ciriello, V.M., Snook, S.H., Hashemi, L., Cotnam, J., 1999. Distributions of manual material handling task parameters. International Journal of Industrial Ergonomics 24, 379-388.
[12]Garg, A., Chaffin, D.B., Herrin, G.D., 1978. Prediction of metabolic rates for manual materials handling jobs. American Industrial Hygiene Association Journal 39(8), 661-674.
[13]Borg, G.., 1985. An introduction to Borg's RPE scale, Ithaca, NY, Movement Publications.
[14]Hutchinson, J.C., Tenenbaum, G., 2006. Perceived effort – Can it be considered gestalt? Psychology of Sport and Exercise 7, 463-476.
[15]Wu, S.P., 1997. Maximum acceptable weight of lift by Chinese experienced male handlers. Applied Ergonomics 28(4), 237-244.
[16]Wu, S.P., 2003. Maximum acceptable weight for asymmetric lifting of Chinese females. 2Applied Ergonomics 34, 215-224.
[17]Chung, H.C., Wang, M.J., 2001. The effects of container design and stair climbing on maximal acceptable lift weight, wrist posture, psychophysical, and physiological responses in wafer-handling tasks. Applied Ergonomics 32, 593-598.
[18]Li, K. W., Yu, R-f, Han, X. L., 2007. Physiological and psychophysical responses in handing maximum acceptable weights under different footwear-floor friction conditions. Applied Ergonomics 38, 259-265.
[19]Deeb, J.M., 1999. Muscular fatigue and its effects on weight perception. International Journal of Industrial Ergonomics 24, 223-233.
[20]Spielholz, P., 2006. Calibrating Borg scale ratings of hand force exertion. Applied Ergonomics 37, 615-618.
[21] Chiou, S-Y, Bhattacharya, A., Succop, P.A. 2000. Evaluation of Workers' perceived sense of slip and effect of prior knowledge of slipperiness during task performance on slippery surfaces. American Industrial Hygiene Association Journal 61, 492-500.
[22] American Society for Testing and Materials, F-1677-05, 2005. Standard method of test for using a portable inclinable articulated strut slip tester (PIAST), Annual Book of ASTM Standards. vol. 15.07. West Conshohochen, PA, American Society for Testing and Materials.

[23]Garg, A., Saxena, U., 1982. Maximum frequency acceptable to female workers for one-handed lifts in the horizontal plane. Ergonomics 25(9), 839-853.
[24]Genaidy, A.M., Asfour, S.S., Khalil, T.M., Waly, S.M., 1985. Physiologic issues in manual materials handling. In R.E. Eberts and C. G. Eberts (eds), Trends in Ergonomics/Human Factors II (Amsterdam: Elservier), 571-576.
[25]Hagen, K.B., Hallẻn, J., Harms-Ringdahl, K., 1993. Physiological and subjective responses to maximal repetitive lifting employing stoop and squat technique. European Journal of Applied Physiology 67(4), 291-297.
[26]Chen, C.W., Chen, C.Y., 2004.Musculoskeletal disorders and workplace risk factors of construction workers. Institute of Occupational Safety & Health Journal 12, 60-72 (in Chinese).
[27]Chen, Y.L., 2000. Optimal lifting techniques adopted by Chinese men when determining their maximum acceptable weight of lift. American Industrial Hygiene Association Journal 61(5), 642-648.
[28]Dempsey, P. G., 1998. A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. Ergonomics 41(1), 73-88.
[29]Wang, M.J., Chung, H.C., Chen, H.C., 2000. The effect of handle angle on MAWL, wrist, posture, RPE, and heart rate. Human Factors 42(4), 553-565.

附件二

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

達成目標 – 研究依原計畫進行，除了期刊論文發表部分以外，預期目標皆以達成。

☐ 未達成目標（請說明，以 100 字為限）

☐ 實驗失敗

☐ 因故實驗中斷

☐ 其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：☐已發表 ☐未發表之文稿 ■撰寫中 ☐無

專利：☐已獲得 ☐申請中 ☐無

技轉：☐已技轉 ☐洽談中 ☐無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本計畫為三年計畫，已完成規畫之相關實驗，並且完成報告撰寫。三年期間總計有 8 名研究生及十餘名大學部學生全部或部分參與本研究，因此研究提供了學生很好的訓練機會。目前已發表兩篇經 EI 檢索的國際研討會論文，相關期刊論文及第三篇研討會論文仍在撰寫中。

附件四

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：___年___月___日

計畫編號	NSC 97－2221 － E－ 216－028 －MY3		
計畫名稱	鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響		
出國人員姓名	李開偉	服務機構及職稱	中華大學工業管理系教授
會議時間	2010年8 月19日至2010年8 月22	會議地點	Providence, RI, USA
會議名稱	34th Annual Meeting of America Society of Biomechanics		
發表論文題目	SLIP-RESISTANCE AND ABRASION OF NEW & USED SHOE SOLES		

一、參加會議經過

This conference was held in Brown University in Rhode Island. The theme was BIOMECHANAICS. Many participants were scientists in mechanical engineering, biomedical engineering, and medical science. There were some presentations in ergonomics. My paper was accepted as poster presentation. So, I had a poster presented in the conference.

二、與會心得

The conference provided an excellent opportunity for the participants to meet friends and colleagues from North America and Europe. It was good to meet people around and to exchange ideas in research.

三、考察參觀活動(無是項活動者略)

四、建議

五、攜回資料名稱及內容: a disc containing the proceedings of the conference

六、其他

SLIP-RESISTANCE AND ABRASION OF NEW & USED SHOE SOLES

Kai Way Li

Chung Hua University, Hsin-Chu, Taiwan, ROC
email: kai@chu.edu.tw

INTRODUCTION

The significance of slipping and falling has been well-established in the literature [1-3]. The factors affecting the slip-resistance of footwear such as footwear and floor materials, floor surface conditions, and shoe sole tread design have been discussed in the literature [4, 5]. However, most of the investigations were conducted using new footwear and floor materials. The new and used footwear may have different slip-resistance and other features. The objective of this study was to compare the coefficient of friction (COF) and abrasion of new and used outsoles for two types of footwear.

METHODS

Two type of footwear commonly worn both at workplace and daily activities were tested. One was a work shoes with hard rubber soles. The soles of rubber-soled shoes have a high Shore-A hardness value of 79.9 (±1.5). The other type of footwear was a sneaker with a shoe sole material of EVA with a shore-A hardness of 28.4 (±1.5).

Twenty adult male subjects were recruited for footwear usage test. These subjects were split into two groups. One group included office staffs in an organization. The other group comprised of college students. The age, stature, and body weight for the office clerks were 42.8 (±9.7) yrs, 168.7 (±7.7) cm, and 73.7 (±2.7) kg, respectively. The age, stature, and body weight for the college students were 22.0 (±1.1) yrs, 168.6 (±6.6) cm, and 73.7 (±17.3) kg, respectively.

The experiment involved the human subjects encompassed a longitudinal study. Each subject received one pair of shoes which fitted his feet size. The rubber-soled shoes with leather topping were distributed to the office clerks and the EVA-soled sneakers were distributed to the college students. The subjects were required to wear the experimental shoes for eight hours per day and three says per week (or equivalent to 24 hours per week) for 26 weeks. Each subject have worn the test shoes for at least 624 (26 week *3 day *8 hour) hours during the experiment. The subjects returned the shoes at the end of the test period. Ten shoe sole samples of each type of the used were prepared for the abrasion and COF measurements. Ten shoe sole samples for each type of new shoes were also prepared for the COF and abrasion measurements.

A NBS Shoe Sole Abrasion Tester was used to measure the abrasion of the sole samples. Measurement of abrasion followed those in the ASTM-D1630 standard [6]. Friction measurements of the shoe soles were conducted on both the terrazzo and vinyl floors. The R_a, also known as the center line average of surface heights (CLA), for the vinyl and the terrazzo floors were 0.66 (±0.23) μm and 1.12 (±0.33) μm, respectively. The surface conditions were either dry or wet. A Brungraber Mark II slipmeter was used for friction measurements. The standard test method published by the American Society for Testing and Materials [7] was adopted. The measurement protocol refined by Chang [8] was also used.

RESULTS AND DISCUSSION

Figure 1 show the mean (±std) COF for the new and used shoe soles under the floor, footwear, and floor surface conditions. Pair-wised student t-tests were conducted to compare the differences in COF between the new and used shoe soles for each floor-footwear-surface condition. The results of all the t-tests were statistical significant ($p<0.001$). The new shoe soles had significant higher COF then those of the used ones except for the wet vinyl and terrazzo floors tested using the rubber soles.

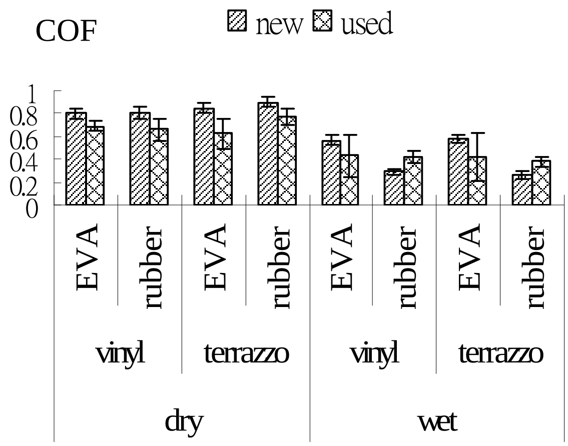

Figure 1: COF for the new and used shoe soles under floor, shoe sole, and surface conditions.

The abrasive indexes of the sole samples are shown in Figure 2. Pair-wised student t-tests were conducted to compare the difference in abrasive index between the new and used shoe sole for both of the rubber- and EVA-soled samples. The results for both tests did not reach the α=0.05 significance level. The difference between rubber and EVA samples for both the new and used samples were also tested. For both the new and used samples, the abrasive indexes for rubber were significantly (p<0.0001) higher than those of the EVA samples.

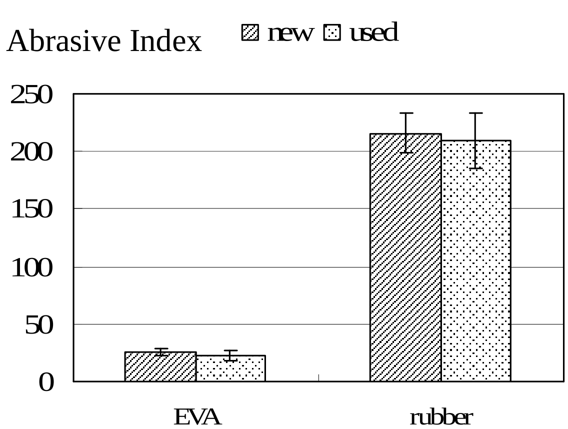

Figure 2: Abrasive index for new and used shoe soles for the types of footwear materials tested.

On dry vinyl and terrazzo floors tested, the COF values decreased after a six month usage for both of the rubber and EVA samples. The COF values also decreased for the same period for EVA samples under wet conditions on both floors. The COF of the used rubber samples increased, however, on wet vinyl and terrazzo floors as compared to their new counterparts.

CONCLUSIONS

The differences of abrasion between new and used shoe soles were not statistically significant. The used shoe soles, however, had significant lower COF values than the new ones except the rubber soles tested on wet vinyl and terrazzo floors.

REFERENCES

1. Leamon TB, Murphy, PL, *Ergonomics* **38(3)**, 487-498, 1995.
2. Tisserand M. *Ergonomics* **28**, 1027-1042, 1985.
3. Strandberg L.*Ergonomics* **28**, 131-147, 1985.
4. Li KW et al., *Saf Sci* **42**, 547-565, 2004.
5. Li KW, Chen CJ, *Saf Sci* **43(7)**, 391-405, 2005.
6. American Society for Testing and Materials, F-1630-07, *Annual Book of ASTM Standards.* West Conshohochen, PA, 2007.
7. American Society for Testing and Materials, F-1677-05, *Annual Book of ASTM Standards*. 15.07. West Conshohochen, PA, 2005.
8. Chang WR, *Saf Sci* **40**, 593-611, 2002.

ACKNOWLEDGEMENTS

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附件四

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：___年___月___日

計畫編號	NSC 97－2221 － E－ 216－028 －MY3		
計畫名稱	鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響		
出國人員姓名	李開偉	服務機構及職稱	中華大學工業管理系教授
會議時間	2010 年 12 月 29 日至 2010 年 12 月 31	會議地點	中國廈門
會議名稱	IEEE 17th International Conference on Industrial Engineering & Engineering Management		
發表論文題目 1	A Study of Combined Manual Materials Handling Tasks under Footwear and Lifting and Lowering Height Conditions		
發表論文題目 2	Slipping Time and Velocity of Footwear Samples in Friction Measurements		

一、參加會議經過

I went to this conference with five of my students. This was the first time we went to Xiamen. The opening ceremony was held in the first day in Xiamen Institute of Science & Technology. There were three keynote speeches. The third one was given by an Indian professor talking about musculoskeletal disorders and manual material handlings research in India. The scientific sessions were held in the 2nd and 3rd day.

二、與會心得

The conference provided an excellent opportunity for the participants, especially my students, to meet friends and colleagues from many Asian countries and from the west. It was good to meet people around and to exchange ideas in research.

三、考察參觀活動(無是項活動者略)

四、建議

五、攜回資料名稱及內容: a disc containing the proceedings of the conference

六、其他

A Study of Combined Manual Materials Handling Tasks under Footwear and Lifting and Lowering Height Conditions

Kai Way Li*, Shu-Yu Ho, Chi Fung Liu
Department of Industrial Management, Chung Hua University, Hsin-Chu, Taiwan

1

Abstract - **A study on combined manual materials handling tasks performed on floors under three footwear and four lifting and lowering height conditions. Twelve male subjects participated in the study. The maximum acceptable weight of handling, including lifting, carrying for 3 m, lowering, and walking 3 m back at 2 per minute was determined. The subject then performed the same tasks for 10 minutes. The VO_2, heart rate, and rating of perceived exertion for whole body strain were measured. The results showed that the effects of footwear on the maximum acceptable weights of handling (MAWH), heart rate, and VO_2 were not significant. The effects of lifting and lowering height on all dependent variables except rating of perceived exertion were statistically significant ($p \leq 0.027$). Lifting from the floor and lowering on the floor condition was the most stressful condition than all other lifting and lowering condition. The subjects had the lowest MAWH on this condition. In addition, lifting from the floor and lowering on the floor condition resulted in the highest physiological responses including both VO_2 and heart rate. The effects of lifting and lowering height on RPE was, however, not significant. The implication of this study was that lifting and lowering height should be regarded as one of the major job factors in designing MMH tasks as it affected physiological responses of the subjects. This is consistent with the findings in the literature.**

Keywords - **manual materials handling, physiological response, subjective rating.**

I. INTRODUCTION

Musculoskeletal problems are very common in industries. In a survey conducted on construction sites in northern Taiwan [1], ninety-seven percent of the interviewees had experienced musculoskeletal symptoms over the previous 12 months. Half of these interviewees had their symptoms treated by medical personnel, with low back pain as the leading body symptom reported. Aches in the upper extremities were also very common [2], suggesting the urgent need for investigating safety and health issues among these workers.

The MMH tasks are very common on construction sites and on other types of workplaces [3], and are one of the major contributors for musculoskeletal symptoms for workers [1]. Workers manually handle construction materials, including cement, brick, steel, wood, and others [4]. The MMH tasks at construction sites normally have a high degree of variability, both in duration and content [1, 5, 6]. This complexity in construction work makes ergonomics interventions much more complicated as compared to those in the manufacturing and service sectors.

One of the most widely accepted approaches in designing MMH tasks is to design or modify a job so as not to exceed the capabilities of the materials handlers [7-11]. Physiological measures are one of the scientific means to evaluate the physical burdens and capabilities of workers in MMH tasks under various job conditions. In the physiological approach, a job is usually divided into simple individual tasks, and the physiological cost of the job is assumed to be the sum of the energy expenditures of these individual tasks. Many researchers have developed regression equations to predict oxygen consumption using personal, task, and workplace variables based on this assumption. The most comprehensive and flexible predictive equations in the MMH tasks were developed in 1978 by Garg et al [12].
Subjective measures may be used to quantify the physical strain caused by physical activities. The ratings of perceived exertion (RPE) developed by Borg [13] has been one the most commonly used subjective measures in assessing the whole body and segmental strain. The RPE is constructed so that the ratings, 6 to 20, are linearly related to the heart rate expected for that level of exertion. As indicated by Hutchinson and Tenenbaum [14], a single measure of RPE is insufficient to capture the whole range of perceptual sensations that people experience when exercising or being physically active. There are numerous examples of using the RPE as supplementary measures in addition to some objective measures in studying the MMH tasks [15-18] and other physical phenomena and activities [19-20]. The objective of the study was to determine the maximum acceptable weight of handling when performing combined manual materials handling tasks and to determine the physiological and perceptual responses of the subjects in performing such a task under different footwear and lifting and lowering height conditions.

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*corresponding author: Kai Way Li is with the Department of Industrial Management, Chung Hua University, Hsin-Chu, Taiwan (phone: +886-3-518-6583; fax: +886-3-518-6575; e-mail: kai@chu.edu.tw). This research was financially support by the National Science Council of the ROC under grant NSC 97-2221-E-216-028-MY3.

II. METHODOLOGY

The experiment was conducted in a laboratory. The temperature and relative humidity in the laboratory ranged 21 to 23 °C and 47% to 64%, respectively.

A. *Subjects*

Twelve male college students, free from any cardiovascular and neuro-musculoskeletal disorders were recruited for this study. Their mean (±std) age, height, body weight, and resting heart rate were 21.0 (±0.7) years, 172.8 (±6.3) cm, 66.3 (±11.1) Kg, and 79.2 (±7.9) beat/min, respectively. All participants signed an informed consent, and were compensated financially for their participation in the study.

B. *Footwear and floor*

The experiment was conducted on a steel walkway. The subjects were required to wear shoes with one of the three soling materials: rubber, blown rubber (RB), and cloth. The friction coefficients between the steel surface and the rubber, RB, and cloth were 0.73, 0.61, and 0.2, respectively.

C. *Manual Materials Handling Tasks*

A plastic container with handles commonly used in local industry was used. Sand bags of 0.1, 0.2, 0.5, and 1 kg were prepared as the materials to be handled. The subject was required to lift the container with a certain amount of weight, from a height to his elbow height and carry it for 3 m, then lower the container onto a certain height. The subject then walked back 3 m, empty-handed, to the original starting position. In other words, one task included a lifting, carrying for 3 m, lowering, and walking empty-handed for 3 m. The frequency of this task was 2 per minute. The lifting and lowering heights included lifting from floor and lowering onto floor (F-F), lifting from floor and lowering on the knuckle height (F-K), lifting from knuckle height and lowering on the floor (K-F), and lifting from the knuckle height and lowering onto the knuckle height (K-K). The walking speeds of the subjects were not controlled. However, they were required to complete two tasks each minute and were instructed to maintain consistent working and walking pace during the experiment. Fig. 1 shows the materials handling task of one subject.

D. *Procedure*

All subjects were instructed to refrain from heavy physical activity before attending the experiment.

Fig. 1 Materials handling task

Before the experiment, the resting heart rate of the subject was measured and the researcher explained the purposes and procedure of the study to the subject. Each session started with the determination of the maximum acceptable weight of handling (MAWH). The MAWH was the terminology used to indicate the maximum acceptable weight that a subject could handle under the lifting, carrying, lowering, and walking back to the origin. This terminology has been used in the previous study [18]. The subject started to handle an initial weight following the described protocol in the previous section after a 5-minute break. The initial weight was in the range of 6 to 12 kg. In the experiment, an initial weight was randomly assigned using a weight either the lower limit or the upper limit. Approximately half of the trials started at a weight near the lower limit while the other half started at a weight near the upper limit.

The subject took a ten minutes break after he determined his WAWH. He, then, put on a K4b2® metabolic measurement unit and a Polar® heart rate monitor. The subject started a same material handling tasks with a load of his MAWH for ten minutes. His VO_2 and heart rate during this period were recorded. The means of the last five minutes were used for statistical analysis. After the experiment, the subject reported his perceived physical exertion for the MMH task been performed using a Borg's RPE Scale [13].

E. *Data analysis*

The experiment was conducted using a two-factor completely randomized design. The factors were the footwear and the lifting/lowering height. A total of 144 (3 footwear × 4 lifting/lowering heights × 12 subjects) trials were performed. Both the descriptive statistical analysis and analysis of variance (ANOVA) were performed. Tukey's HSD test was conducted if the factor was found statistically significant at α =0.05 level. The statistical analyses were performed using the SPSS® 12.0 computer software.

III. RESULTS

The ANOVA results for the dependent variables of the study were shown in TABLE I. For MAWH, the ANOVA results of the study showed the effect of footwear was not statistically significant. The effect of lifting and lowering height was significant (p<0.0001). The mean (±std) MAWH for F-F, F-K, K-F, and K-K were 7.52 (±1.38), 8.35 (±1.41), 8.20 (±1.40), and 9.02 (±1.42) kg, respectively (see Fig. 2). Tukey's HSD test results showed that F-F condition had significant higher MAWH than that of the K-K condition.

For VO_2, the ANOVA results of the study showed the effect of footwear was not statistically significant. The effect of lifting and lowering height was significant (p<0.0001). The mean (±std) VO_2 for F-F, F-K, K-F, and K-K were 721.53 (±160.47), 652 (±129.18), 605.21 (±107.49), and 573.49 (±121.16) ml/min, respectively (see Fig. 3). Tukey's HSD test results showed that F-F condition had significant higher VO_2 than those of all other lifting and lowering conditions. The difference among F-K, K-F, and K-K conditions were not statistically significant.

For heart rate, the ANOVA results of the study showed the effect of footwear was not statistically significant. The effect of lifting and lowering height was significant (p=0.027). The mean (±std) heart rate for F-F, F-K, K-F, and K-K were 100.93 (±9.76), 98.59 (±10.38), 95.90 (±9.53), and 94.36 (±8.70) beats/min, respectively (see Fig. 4). Tukey's HSD test results showed that F-F condition had significant higher heart rate than those of all other lifting and lowering conditions. The difference among F-K, K-F, and K-K conditions were not statistically significant.

For RPE, the ANOVA results of the study showed the effect of both footwear and lifting and lowering height were not statistically significant. The range of RPE was between 9 and 15. Most trials were rated as 11 or 12 indicating that the subjects felt the task was light.

TABLE I
ANOVA RESULTS

	Source	df	MS	p-value
MAWH	Footwear	2	3.1	0.22
	LL height	3	13.6	0.000
VO_2	Footwear	2	4079	0.79
	LL height	3	148921	0.000
HR	Footwear	2	30.4	0.73
	LL height	3	304.4	0.027
RPE	Footwear	2	0.9	0.53
	LL height	3	0.3	0.89

LL height: lifting & lowering height

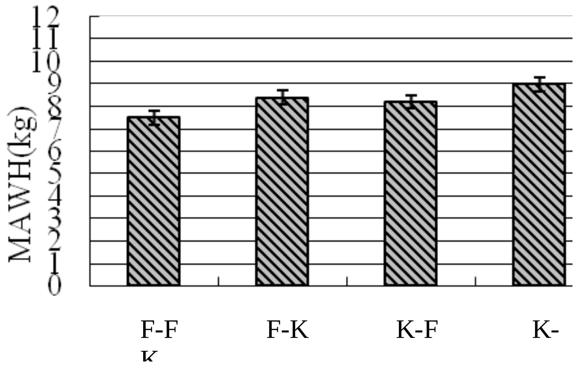

Fig. 2 MAWH under different lifting and lowering heights

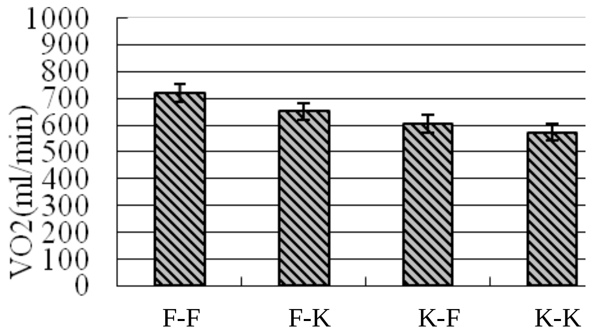

Fig. 3 VO_2 under different lifting and lowering heights

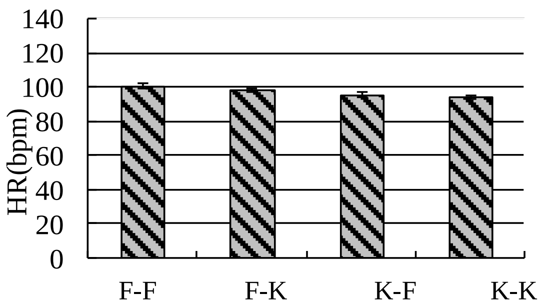

Fig. 4 Heart rate (beat/minute) under different lifting and lowering heights

IV. DISCUSSIONS

The results of the study indicated that footwear did not affect the MAWH, VO2, heart rate, and RPE significantly. Lifting and lowering height, however, was a significant factor affecting the MAWH, VO2, and heart rate. Lifting from the floor and lowering onto the floor was the most stressful condition among all lifting and lowering conditions. This was consistent with the finding in the literature [5-6, 23-25] that either squatting or bending toward floor level to reach the weight and lift it resulted in high stress on the physiological system which may be monitored from the physiological measures such as VO_2 and heart rate.

The two factors studied did not affect RPE significantly. This is reasonable as the subjects were handling a weight which they perceived as the weight they could handle in an eight hour shift without over-stress themselves. The RPE ranged from 9 to 15 but most trials had an RPE of either 11 or 12. The subject felt that the materials handling tasks were light as they were handling a weight for only 10 minutes which was determined on an eight-hour basis.

V. CONCLUSION

An experiment was conducted to test the maximum acceptable weight of handling. The subjects were, then, requested to handle the weight for ten minutes. The subjects' VO2, heart rate, and rating of perceived exertion were measured. The results of the study found that lifting and lowering height was a significant factor affecting the MAWH, VO_2, and heart rate. Lifting from the floor level and lowering onto the same level was the most stressful condition and should be avoid in job design.

REFERENCES

[1] C. L. Lee, Y. H. Lee, J. L. Huang, C. Y. Chen, "The study of workers' musculoskeletal disorders in building construction sites," *Institute of Occupational Safety and Health Journal*, vol. 11, pp. 227-236, 2003 (in Chinese).

[2] K. W. Li, "Ergonomic design and evaluation of wire-tying hand tools," *International Journal of Industrial Ergonomics*, vol. 30, pp. 149-161, 2002.

[3] S. P. Wu, C. P. Chiu, "Ergonomics Study of Musculoskeletal Injuries in the Hotel Housekeeping Worker," *Journal of Occupational Safety and Health,* vol. 15, pp. 75-86, 2007.

[4] K. W. Li, C. L. Lee, "Postural analysis of four jobs on two construction sites: an experience of using the OWAS method in Taiwan," *Journal of Occupational Health*, vol. 41, pp. 183-190, 1999.

[5] L. Punnett, V. Paquet, "Ergonomic exposures to construction carpenters and carpentry laborers in tunnel construction," In: Mital, A., et al., Advances in Occupational Ergonomics and Safety I, *Proceedings of the XIth International Occupational Ergonomics and Safety Conference*. IOS Press, Amsterdam, pp. 99-104, 1996.

[6] G. A. Mirka, D. P. Kelaher, D. T. Nay, "Continuous assessment of back stress (CABS): a new method to quantify low-back stress in jobs with variable biomechanical demands," Human Factors, vol. 42(2), pp. 209-225, 2000.

[7] S. H. Snook, "The design of manual handling tasks," *Ergonomics*, vol. 21, pp. 963-985, 1978.

[8] S. H. Snook, "Psychophysical considerations in permissible loads," *Ergonomics*, vol. 28, pp. 327-330, 1985.

[9] T. R.Waters, V. Putz-Anderson, A. Garg, L. Fine, "Revised NIOSH equation for the design and evaluation of manual lifting tasks," *Ergonomics*, vol. 36(7), 749-776, 1993.

[10] V. M. Ciriello, S. H. Snook, "Survey of Manual Handling Tasks," *International Journal of Industrial Ergonomics*, vol. 23, 149-156, 1999.

[11] V. M. Ciriello, S. H. Snook, L. Hashemi, J. Cotnam, "Distributions of manual material handling task parameters," *International Journal of Industrial Ergonomics*, vol. 24, 379-388, 1999.

[12] A. Garg, D. B. Chaffin, G. D. Herrin, "Prediction of metabolic rates for manual materials handling jobs," *American Industrial Hygiene Association Journal*, vol. 39(8), 661-674, 1978.

[13] G. Borg, An introduction to Borg's RPE scale, Ithaca, NY, Movement Publications, 1985.

[14] J. C. Hutchinson, G. Tenenbaum, G, "Perceived effort — Can it be considered gestalt?" *Psychology of Sport and Exercise*, vol. 7, pp. 463–476, 2006.

[15] S. P. Wu, "Maximum acceptable weight of lift by Chinese experienced male handlers," *Applied Ergonomics,* vol. 28(4), 237-244, 1997.

[16] Wu, S.P., 2003. Maximum acceptable weight for asymmetric lifting of Chinese females. 2Applied Ergonomics 34, 215-224.

[17] H. C. Chung, M. J. Wang, "The effects of container design and stair climbing on maximal acceptable lift weight, wrist posture, psychophysical, and physiological responses in wafer-handling tasks.," Applied Ergonomics, vol. 32, pp. 593-598, 2001.

[18] K. W. Li, R-f Yu, X. L. Han, "Physiological and psychophysical responses in handing maximum acceptable weights under different footwear-floor friction conditions," *Applied Ergonomics,* vol. 38, pp. 259-265, 2007.

[19] J. M. Deeb, "Muscular fatigue and its effects on weight perception," *International Journal of Industrial Ergonomics*, vol. 24, 223-233, 1999.

[20] P. Spielholz, "Calibrating Borg scale ratings of hand force exertion," *Applied Ergonomics*, vol.37, pp. 615-618, 2006.

[21] A. Garg, U. Saxena, "Maximum frequency acceptable to female workers for one-handed lifts in the horizontal plane," *Ergonomics*, pp. 25(9), 839-853.

[22] A. M. Genaidy, S. S. Asfour, T M. Khalil, S. M. Waly, "Physiologic issues in manual materials handling," In R.E. Eberts and C. G. Eberts (eds), *Trends in Ergonomics/Human Factors II* (Amsterdam: Elservier), pp. 571-576, 1985.

[23] K. B. Hagen, J. Hallėn, K. Harms-Ringdahl, "Physiological and subjective responses to maximal repetitive lifting employing stoop and squat technique," *European Journal of Applied Physiology*, vol. 67(4), pp. 291-297, 1993.

[24] C. W. Chen, C. Y. Chen, "Musculoskeletal disorders and workplace risk factors of construction workers," *Institute of Occupational Safety & Health Journal*, vol. 12, pp. 60-72, 2004 (in Chinese).

[25] Y. L. Chen, "Optimal lifting techniques adopted by Chinese men when determining their maximum acceptable weight of lift," *American Industrial Hygiene Association Journal*, vol. 61(5), pp. 642-648, 2000.

[26] P. G. Dempsey, "A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks," *Ergonomics,* vol. 41(1), pp. 73-88, 1998.

[27] S. P. Wu, J. P. Chen, "Effects of the adjustment period on psychophysically determined maximum acceptable weight of lift and the physiological cost," *International Journal of Industrial Ergonomics*, vol. 31, pp. 287-294, 2003.

[28] M. J. Wang, H. C. Chung, H. C M.J. Chen, "The effect of handle angle on MAWL, wrist, posture, RPE, and heart rate," Human Factors, vol. 42(4), pp. 553-565, 2000.

Slipping Time and Velocity of Footwear Samples in Friction Measurements

K. W. Li[1], L. Liu[2], C-Y Chen[2], H. F. Tsai[1],Y. T. Chen[1]
[1]Department of Industrial Management, Chung-Hua University, Hsin-Chu, Taiwan
[2]Institute of Occupational Safety & Health, Taipei, Taiwan

Abstract - **A friction measurement experiment was conducted using the Brungraber Mark II slipmeter. The coefficient of friction (COF), the time and velocity of slipping of the footwear sample on the floor were measured under four floors and two surface conditions. Two operators performed the measurements separately. The results showed that there were no significant differences between the two operators in measuring all the dependent variables. The ANOVA results showed that the floor, surface conditions, and their interactions affected the COF and velocity of slipping significantly ($p<0.05$). The Pearson's correlation coefficient between the COF and the slipping velocity of the footwear sample was -0.81 ($p<0.0001$). This implied that fast slipping was associated with low COF value. The slipping time and velocity of the footwear sample provided a basis to train the operators in making the slip and non-slip judgment. They are also helpful in developing an automatic friction measurement device that require slip/non-slip judgment.**

Keywords - **slips & falls**, **friction measurement, slip velocity, Brungraber Mark II.**

I. INTRODUCTION

Slip and fall accidents create significant occupational safety & health problems [1][2][3]. Slips normally occur when the friction at the footwear-floor interface is inadequate. Determination of coefficient of friction (COF), or friction measurement, has been one of the major approaches in studying slip & fall incidences. Friction measurements on horizontal surfaces, especially under liquid-contaminated conditions, both in laboratory and in the field have been reported. It was also known that most slipping and falling occurred on horizontal surfaces [2][4]. Measurement of floor slip slipperiness is very importance in determining the risk of slipping and falling incidents.

Friction measurement is one of the major approaches in determining floor slipperiness[5]. Even though numerous friction measurement devices, or slipmeters, have been designed and fabricated, none of them has been universally accepted as a perfect one in determining floor slipperiness[6][7]. All of the friction measurement devices have advantages and disadvantages. Different friction measurement devices provide different readings even at the same footwear material-floor interface.

The Brungraber Mark II (see Fig. 1) has been one of the friction measurement devices commonly used in the USA [7][8]. The BM II is a portable, inclinable, articulated strut slip tester (PIAST). The operating principle of this tester is to simultaneously apply forces parallel and normal to a floor surface by impacting a footwear pad on the floor. A weight of 4.54 kg drives an inclined-strut to impact the floor surface at an inclined angle to the vertical. The footwear sample is approximately 7.62 cm × 7.62 cm and is within a height of 3.175 to 6.35 mm from the floor surface. The angle of the strut is increased until a slip occurs on impact. The starting angle should be smaller than the angle at which a slip is anticipated and the angle is increased until a slip occurs. The tangent of the angle is the COF marked on the tester. The standard test method for the BM II was proposed by the American Society of Testing and Materials (ASTM) [9]. According to the ASTM standard, it might be necessary to average the maximum COF that a non-slip occurs and the minimum COF that a slip occurs.

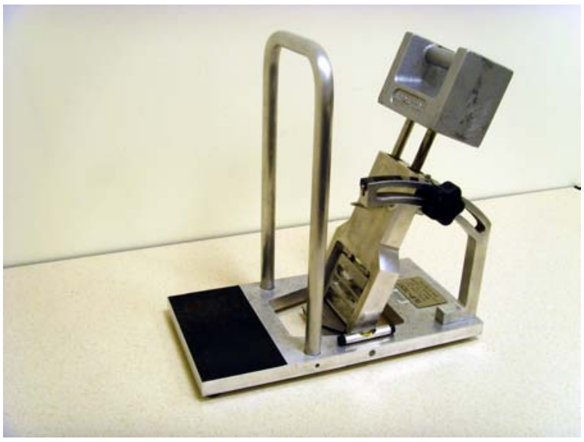

Fig. 1 Brungraber Mark II slipmeter

The COF values reported by the Mark II were compared with the horizontal-vertical force ratio (F_H/F_V) obtained from a force platform [10][11]. The results showed that the COF obtained directly from the Mark II and from the force plate measurements showed good agreement over a range of floor surfaces and contaminants for both non-slip and barely slip conditions. The Mark II was also shown to have a good correlation (r>0.954) with the dynamic friction coefficient measured with a dynamic apparatus designed to simulate a slip [10]. Comparisons between the results obtained with the BM II and other friction measurement devices were reported by [10][11][12][13]. Comparisons between the readings of the Mark II and subjective ratings of floor slipperiness have been reported by Chang et al. [14] and Li et al. [15].

Operation of the Mark II requires repetitive strikes of the footwear pad on the floor for a single reading. One of the disadvantages of the Mark II is that the operator needs to lift a 4.54 kg weight and releases it in every trial. The operation of the BM II followed the requirements in the ASTM standard (F-1677) [9]. The measurement protocol used by Chang [8] was adopted. In this protocol, the measurement started at a low COF and was increased by 0.05 if a non-slip persisted. If the COF was higher than 0.15, there were at least three non-slips before a slip occurred. After a slip occurred, the COF was reduced by 0.01 as long as the slip persisted. When a non-slip occurred again, the measurement stopped. The COF of the last slip was recorded as the COF value for the measurement. The judgment of slip and non-slip upon the impact of the footwear pad on the floor followed that of Chang [8].

When operating the BM II, the footwear sample may slip fast or slow upon impact on the floor. Chang [8] recommended a fast slip as a slip and a slow slip as a non-slip. This, however, involves subjective judgment of the footwear slipping velocity of the sample upon impacting the floor. Theoretically, the data of slipping velocity or the time required for a fast slip will be helpful in training the operator or even in determining the friction coefficient more reliably. The purpose of this study was to determine the velocity of the footwear sample on the floor when measuring the friction coefficient under four floors, two surface conditions. It was also desired to test the difference of the velocity between two operators.

II. METHODOLOGY

1) *Slipmeter Testing Protocol & Operator*

A friction measurement experiment was conducted in the laboratory using the BM II slipmeters (Slip-Test Inc., Spring Lake, NJ). Operation of the BM II followed that of the ASTM standard (ASTM, F-1677) [9]. A photocell activated timer was designed to measure the time upon the impact of the footwear sample till the footwear sample stopped on the floor. The time and velocity of the slipping of the footwear sample on the floor were measured when the COF of the last slip was recorded in the measurement.

2) *Footwear Materials & Floors*

A flat Neolite footwear sample provided by the supplier of the BM II was used in this study. Sanding of the footwear pad is recommended to maintain a consistent surface condition. Sanding papers of 400 grits were used. The footwear pad sanding protocol recommendations by Chang [8] were adopted. The floors used in the friction measurements included steel, ceramic, plastic and terrazzo tile.

3) *Surface Conditions*

The surface conditions of the friction measurement included dry and wet conditions. For the dry condition, dry clean floors were measured. For the wet conditions, water was applied to resemble actual wet floor surface conditions. Water was replenished in the footwear striking area during repeated strikes under the wet condition. The amount of water for each replenishment was 10 ml. This amount of water and the replenishment procedure were adopted in previous studies [13][14][15][16][17][18]. Both the footwear pad and floor were cleaned up after each measurement.

4) *Experimental Design*

The experiment involved four floors and two surface conditions. Eight replicates were conducted for each treatment. The same experiment was performed by two operators separately. This comprised 128 trials (2×4×8×2). The COF value, the time of the slipping of the footwear sample on the floor was measured. The velocity of the slipping of the footwear sample was calculated by dividing the distance of the footwear sample movement by the time of the slipping. Both the difference in COF and time of slipping between the two operators were tested using a pair-wised t-test. Analysis of variance (ANOVA), descriptive statistics and correlation analysis were performed. All data analyses were conducted using the SAS® statistical analysis software.

III. RESULTS

The results of the pair-wised t-test for both the COF and time of slipping between the two operators were not statistically significant. Operator was, then, not considered a factor in the study and the data from the two operators were pooled in the ANOVA. A two-factor ANOVA with 16 replicates was performed for both the COF and the velocity of slipping of the footwear sample. The results showed that the effects for both the floor and surface on COF were statistically significant (p<0.0001). The interaction of this two factors was also significant (p<0.0001). Fig. 2 shows the means and standard deviations of the four floors under dry and wet conditions. It was apparent that dry surfaces had significant higher COF values than those of the wet surfaces for all floors. The ceramic had the highest COF among all floors. The steel and terrazzo were the next. The plastic floor had the lowest COF. On wet surfaces, the ceramic still had the highest COF readings. The plastic, however, had the second highest COF. Both the steel and the terrazzo had the lowest.

The ANOVA results for the velocity of slipping showed that the both the floor and surface effects were statistically significant at p<0.01 and p<0.0001, respectively. The effects of their interaction was significant at p<0.05. Fig. 3 shows the slipping velocity of

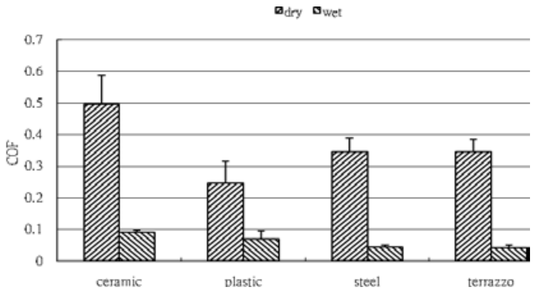

Fig. 2. COF values under floor and surface conditions.

the footwear sample under floor and surface conditions. It was apparent that the velocities of slipping on wet surfaces were significantly higher than those of the dry surfaces. On wet surfaces, ceramic and steel had significant (p<0.05) higher velocity than those of the plastic and terrazzo floors. The difference between ceramic and steel floors was not significant. Neither was the difference between plastic and terrazzo floors significant. The velocity on wet floor was approximately in the range of 60 to 69 cm/sec. On dry surfaces, there was no significant difference between any of the two floors tested. The velocity was approximately in the range of 38 to 42 cm/sec.

Fig. 3 shows the time of slipping of the footwear during the measurement. On dry surfaces, the time were significantly (p<0.0001) higher than those of the wet surfaces for all four floors. For dry surfaces, the time of slipping ranged from 112 to 125 ms. For wet surfaces, the time of slipping ranged from 70 to 80 ms.

The Pearson's correlation coefficient between the COF and the time and velocity of slipping was 0.76 (p<0.0001) and -0.81 (p<0.0001), respectively. This implies that high slipping velocity or short slipping time was associated with low COF value. This was consistent with the results in the ANOVA.

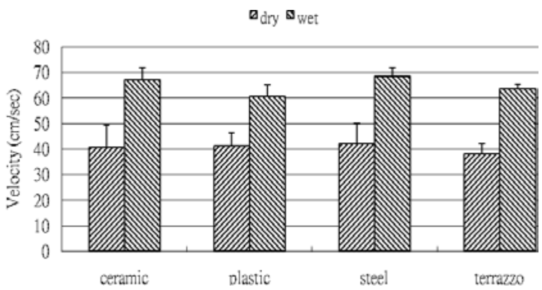

Fig. 3. Slipping velocity (cm/sec) of the footwear sample under floor and surface conditions.

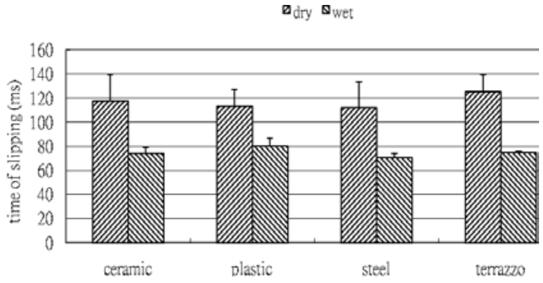

Fig. 4. Time of slipping (ms) under floor and surface conditions.

A simple linear regression model was established to describe the relationship between the COF and the slipping velocity of footwear sample using the following equation:

$$COF = \beta_0 + \beta_1 \times \text{velocity}$$

where β_0 and β_1 are regression coefficients. The estimated parameters for β_0 and β_1 were 0.719 and -0.009, respectively. The two-tailed t-test for the two regression coefficients were both significant at p<0.0001. The coefficient of determination, or R^2, of the model was 0.66 indicating that 66% of the variation of COF readings may be explained the slipping velocity of the footwear sample.

IV. DISCUSSION

Operation of the BM II requires repetitive strikes of the footwear on the floor. The operator needs to judge whether a slip or a non-slip occurs. Such a judgment is more or less subjective. A photocell activated timer was fabricated to be used with the BM II slipmeter to measure the time of slip for the footwear sample when measuring the COF. This timer was deigned as an aid to the operator in judging the "fast slip" more reliably. One of the hypotheses of the study was that the slipping velocity of the footwear sample was not COF-dependent. In other words, a constant slipping velocity exists for all footwear, floor, and surface conditions at the minimum COF where a slip did occur. This hypothesis was, however, rejected. The results of the study indicated that the time of slipping, or alternatively the slipping velocity, was COF-dependent. The difference between dry and wet surfaces was significant. This implied that a constant velocity for slip/non-slip judgment does not exist. Even so, the range of the slipping time for those of the dry and wet surfaces still provides hints for an novice operator in making a slip/non-slip judgement.

V. CONCLUSION

In this research, a photocell activated switch timer was used together with the BM II slipmeter in friction measurement. The slipping time and velocity of footwear sample on a BM II slipmeter when a slip occurred at a minimum COF were measure and analyzed. The results showed that the slipping time and velocity of footwear sample on a BM II slipmeter were COF-dependent. A linear regression model was established to describe the relationship between the COF and the slipping velocity. This model was significant at $p<0.0001$ and with an R^2 of 0.66. The model may be used to determine the slipping velocity of the Neolite footwear sample in different COF levels.

REFERENCES

[1] M. P.J. Perkins, "Measurement of Slip Between the Shoe and Ground During Walking," *Walkway Surfaces: Measurement of Slip Resistance,* ASTM STP 649, Carl Anderson and John Senne, Eds, American Society for Testing and Materials, pp. 71–87, 1978.

[2] L. Strandberg, "The effect of conditions underfoot on falling and overexertion accidents," *Ergonomics, vol.* 28, no. 1, pp. 131–147, 1985.

[3] T. B., Leamon, P. L. Murphy, "Occupational slips and falls: more than a trivial problem," *Ergonomics*, vol. 38, no. 3, pp. 487–498, 1995.

[4] T. K. Courtney, G. Sorock, D. P. Manning, J. W. Collins, M.A. Holbein-Jenny, "Occupational slip, trip, and fall-related injuries – can the contribution of slipperiness be isolated?" *Ergonomics*, vol. 44, no. 13, pp. 1118–1137, 2001.

[5] W. R. Chang et al., "The role of friction in the measurement of Slipperiness, Part 1: friction mechanisms and definition of test condition, " *Ergonomics*, vol. 44, no. 13, pp. 1217–1232, 2001.

[6] R. O. Andres, D. B. Chaffin, "Ergonomic analysis of slip-resistance measurement device," *Ergonomics*, vol. 28, 1065–1079, 1985.

[7] W. R. Chang, et al., "The role of friction in the measurement of Slipperiness, Part 2: Survey of friction measurement devices, " *Ergonomics,* vol. 44, no. 13, pp. 1233–1261, 2001.

[8] W. R. Chang, The effects of slip criteria and time on friction measurements, Safety Science, vol., pp. 593-611, 2002.

[9] American Society for Testing and Materials, F-1677-96, Standard method of test for using a portable inclinable articulated strut slip tester (PIAST), *Annual Book of ASTM Standards,* vol. 15.07. West Conshohochen, PA, American Society for Testing and Materials, 2005.

[10]R. Grönqvist, Slips and falls. In S Kumar (ed.), *Biomechanics in Ergonomics*, London: Taylor & Francis. pp. 351–375, 1999.

[11]C. M. Powers, K. Kulig, J. Flynn, J. R. Brault, Repeatability and bias of two walkway safety tribometers, *Journal of Testing and Evaluation*, vol. 27, pp. 368–374, 1999.

[12]R. Grönqvist, M. Hirvonen, A. Tohv, Evaluation of three portable floor slipperiness testers, *International Journal of Industrial Ergonomics,* vol. 25, pp. 85–95, 1999.

[13]W. R. Chang, S. Matz, The slip resistance of common footwear materials measured with two slipmeters, *Applied Ergonomics,* vol. 32, pp. 540–558, 2001.

[14]W. R. Chang, J. P. Cotnam, S. Matz, Field evaluation of two commonly used slipmeters, *Applied Ergonomics*, vol. 34, no. 1, pp. 51–60, 2003.

[15]K. W. Li, W. R. Chang, T. B. Leamon, C. J. Chen, "Floor slipperiness measurement: friction coefficient, roughness of floors, and subjective perception under spillage conditions," *Safety Science*, vol. 42, pp. 547–565, 2004.

[16] W. R. Chang, K. W. Li, Y-H Huang, A. Filiaggi, T. K. Courtney, Assessing floor slipperiness in fast-food restaurants in Taiwan using objective and subjective measures, *Applied Ergonomics*, vol. 35, pp. 401–408, 2004.

[17]K. W. Li, C. J. Chen, The effect of shoe soling tread groove width on the coefficient of friction with different sole materials, floors, and contaminants, *Applied Ergonomics*, vol. 35, pp. 499–507, 2005.

[18]K. W. Li, H. H. Wu, Y. C. Lin, The effect of shoe sole tread groove depth on the friction coefficient with different tread groove widths, floors, and contaminants, *Applied Ergonomics*, vol. 37, pp. 743–748, 2006.

國科會補助計畫衍生研發成果推廣資料表

日期:2011/08/07

國科會補助計畫	計畫名稱: 鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響
	計畫主持人: 李開偉
	計畫編號: 97-2221-E-216-028-MY3　　學門領域: 人因工程與工業設計

無研發成果推廣資料

97 年度專題研究計畫研究成果彙整表

計畫主持人：李開偉 計畫編號：97-2221-E-216-028-MY3

計畫名稱：鞋與地板間抗滑性對於從事人工物料處理活動時之生理與主觀反應之影響

成果項目			量化：實際已達成數（被接受或已發表）	量化：預期總達成數(含實際已達成數)	量化：本計畫實際貢獻百分比	單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
國內	論文著作	期刊論文	0	1	100%	篇	目前一篇期刊論文撰稿中
		研究報告/技術報告	1	1	100%		研究報告已撰寫完畢
		研討會論文	0	2	100%		兩篇研討會論文撰稿中
		專書	0	0	100%		
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		博士生	0	1	0%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
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		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估 ■達成目標 □未達成目標（請說明，以 100 字為限） 　□實驗失敗 　□因故實驗中斷 　□其他原因 說明：
2. 研究成果在學術期刊發表或申請專利等情形： 論文：□已發表 □未發表之文稿 ■撰寫中 □無 專利：□已獲得 □申請中 ■無 技轉：□已技轉 □洽談中 ■無 其他：（以 100 字為限） 目前正依實驗數據撰寫論文，並準備發表事宜
3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限） 本研究探討鞋材與搬物攜行距離對於最大可接受負重的影響，並分析在三種鞋材與三種攜行距離下從事人工勿料處理人員的生理參數與主觀負荷評分的變異行為，研究成果可以提供企業的現場管理人員在設計人工物料處理作業時的設計參考，也可以提供安全衛生人員在評估現場人工物料處理作業之工作負荷與肌肉骨骼傷害風險之依據.