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Objective and subjective measurements of slipperiness in fast-food restaurants in the USA and their comparison with the previous results obtained in Taiwan

Wen-Ruey Chang *, Kai Way Li, Yueng-Hsiang Huang, Alfred Filiaggi, Theodore K. Courtney

Liberty Mutual Research Institute for Safety, 71 Frankland Road, Hopkinton, MA 01748, USA

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Abstract

Floor slipperiness is a critical issue in slip and fall incidents which are a major source of occupational injuries. The objectives of the current study were to investigate if the protocols used in a field study conducted in Taiwan could be used in similar environments in the USA and whether consistent results could be obtained. Protocols used in the field study to investigate floor slipperiness in western-style fast-food restaurants in Taiwan included both objective and subjective measurements. Using the same methods as in Taiwan, friction was measured on tiles in six major working areas of 10 fast-food kitchens in the USA as an objective measurement of slipperiness, while the subjective measurement was employees' ratings of floor slipperiness over the same areas. The Pearson's and Spearman's correlation coefficients in the USA between the averaged friction coefficients and subjective ratings for all 60 evaluated areas across 10 restaurants were 0.33 ($p = 0.01$) and 0.36 ($p = 0.005$), respectively, which were lower than the correlations of 0.49 and 0.45, respectively, obtained in Taiwan. Cultural differences, the amount of water on the floors in the sink areas and the existence of a slip resistant shoe program in one country might be contributors to the lower correlation coefficients in the USA. However, the current study confirmed the results obtained in Taiwan that average friction coefficient and perception values are in fair agreement, suggesting that both might be reasonably good indicators of slipperiness.

* Corresponding author. Tel.: +1 508 497 0219; fax: +1 508 435 8136.
E-mail address: Wen.Chang@LibertyMutual.com (W.-R. Chang).

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1. Introduction

Slips, trips and falls are a serious safety problem in work environments, estimated to account for more than 6 billion US dollars annually in the direct cost of occupational injuries in the USA (Courtney et al., 2001). As reported by Leamon and Murphy (1995), falls on the same level accounted for approximately 65% of claim cases and 53% of claim costs in total direct workers' compensation for occupational injuries due to slips and falls. The majority of falls in the USA and European countries also occur on the same level with slips resulting in roughly 40–50% of same level falls (Courtney et al., 2001).

Leamon and Murphy (1995) reported that the incidence rate of falls on the same level was approximately 4.1 per 100 full-time restaurant employees over a two-year period, leading to an annual cost of approximately US $116 per employee. Within the restaurant industry in the USA, slips and falls led to the second most frequent claims and the most costly claims (Leamon and Murphy, 1995). Slippery floors, typically caused by contaminants such as water and grease, are commonly found in restaurant kitchens (Chang et al., 2003), and are a critical factor for falls on the same level (Chang et al., 2001b).

One of the most common methods of assessing slipperiness is to measure friction between the shoe and floor surfaces (Chang et al., 2001b). The potential risk of slip and fall incidents is usually judged by the levels of coefficient of friction (COF). It is generally assumed that slip and fall incidents are more likely to occur on floors with a low COF. Gait adaptations when people are aware of walking on slippery surfaces cast doubt on the validity of the COF level as a sole indicator of slipperiness (Strandberg, 1985; Leamon, 1992; Grönqvist et al., 2001). Friction variation can also play a role in determining slipperiness in addition to the level of COF. Friction of the floor is highly location (tile) dependent (Leclercq et al., 1997; Chang et al., 2003). Local friction variation could increase the potential for slip and fall incidents (Strandberg, 1985; Pater, 1985; Andres et al., 1992; Grönqvist et al., 2001). A slip and possibly a fall could occur if a person unexpectedly encounters a low friction area without making body posture adjustments.

Most published studies of friction measurements were conducted in laboratories using new floor surfaces and artificial contaminants that might not represent what most employees encounter daily. Realistic conditions of floor surfaces could be better reflected in field studies. However, field studies with friction measurements are rarely reported in the literature. Such studies have focused on an evaluation of floor cleaning (Harrison and Malkin, 1983), implementing a floor improvement program (Ballance et al., 1985), an evaluation of slipmeters (Andres and Chaffin, 1985; Chang et al., 2003), the effects of environmental factors on the measured friction (Leclercq et al., 1997; Leclercq and Saulnier, 2002), the correlation between a perception rating and objective measurements such as the level of COF and surface roughness parameters (Chang et al., 2004; Li et al., 2004), and quantifications of friction variations in fast-food restaurants (Chang et al., 2005).

One of the slipmeters most commonly used to measure friction in a field environment in the USA is the Brungraber Mark II, which is driven by gravity and known as a portable inclinable articulated strut slip tester (PIAST) (Marpet, 1996; Marpet and Fleischer, 1997; Grönqvist et al., 1999; Powers et al., 1999; Chang and Matz, 2001; Chang et al., 2001a;

Chang, 2002; Chang et al., 2003; Chang et al., 2004; Li et al., 2004; Chang et al., 2005). The validity of the results obtained with this slipmeter were summarized by Chang et al. (2004). In a fast-food environment, the standard deviations of the friction coefficient measured with this slipmeter on the same tiles without a sanding between consecutive friction measurements had averages of approximately 0.028 in the grill area (mean 0.67), 0.024 by the fryer and back door (means 0.67 and 0.70, respectively), and 0.021 in the sink area with water contamination (mean 0.26) (Chang et al., 2003).

Perception of floor slipperiness, also essential to assessing slipperiness, could supplement objective measurements of slipperiness including friction measurements. Correlations between the perception and objective measures of slipperiness published in the literature were summarized by Chang et al. (2004). Myung et al. (1993) reported an inverse relationship between the subjective ranking and measured static COF; a lower measured COF value usually resulted in a more slippery subjective ranking. Cohen and Cohen (1994) reported significant disagreements between the measured COF values of the tiles and subjective responses obtained by visual comparison of the 23 tested tiles to a standard tile with a COF of 0.5. Swensen et al. (1992) reported that the correlations between the measured COF and subjective rating of the surface slipperiness of steel beams with different coatings were strong for both ironworkers ($r = 0.75$) and college students ($r = 0.90$). A significant correlation between the subjective evaluation scores of slipperiness and the objective measurements such as the measured COF ($r = 0.97$, $p < 0.05$) and slip distance ($r > 0.99$, $p < 0.01$) was reported by Grönqvist et al. (1993). Li et al. (2004) reported the Spearman's rank correlations in the range of 0.8 to 0.975 between the subjective rating score for slipperiness and friction coefficient measured with Neolite in a university campus under spillage conditions. Chang et al. (2004) reported that the Pearson's and Spearman's correlation coefficients between the subjective rating of slipperiness of major working areas in western-style fast-food restaurants in Taiwan and the level of friction measured in the same working areas were 0.49 and 0.45, respectively, with $p < 0.0001$ for both.

Chang et al. (2004) reported a statistically significant correlation between the perception rating score of slipperiness and friction based on the data collected in 10 western-style fast-food restaurants in Taiwan. The applicability of this relationship between the perception rating score and friction obtained in Taiwan to a similar work environment in the USA could be in question. Additionally, there was an interest in determining the reproducibility of the results of the prior study and, in particular, whether the design would prove successful in a more diverse workforce in a different part of the world. One might expect a consistent general trend, but the magnitude of the relationships might be different although the environments are similar. The objectives of the current study were to investigate if the protocols used in a field study conducted in Taiwan could be used in similar environments in the USA and whether consistent results could be obtained. The same protocols used in the previous study conducted in Taiwan (Chang et al., 2004) were adopted in the current study conducted in a similar type of fast-food restaurant in the USA. The correlations between the perception rating scores and friction obtained from the field studies in these two countries were compared in the current study.

2. Methods

Ten corporately-owned restaurants of a fast-food chain in the USA participated in the current study. Due to a large volume of customers over a short time period, the kitchen floor conditions in this restaurant type during lunchtime represent one of the more heavily contaminated situations in their daily operation. With an attempt to capture lunchtime conditions as closely as possible, objective friction measurements and subjective perception ratings were conducted concurrently in each restaurant on weekdays immediately after the lunch period, starting at approximately 1 pm. Both sets of measures were completed on the same day. No major floor cleaning in these restaurants was performed from the lunch period until the time when friction was measured.

2.1. Slipmeter

Friction was measured with two Brungraber Mark II slipmeters using Neolite test liners, as in Taiwan. The American Society for Testing and Materials (ASTM) publishes the guidelines for operating this slipmeter (ASTM F1677-05, 2005). The details of the refined protocols used in this experiment in operating this slipmeter were outlined in Chang et al. (2004).

2.2. Major working areas and floor tiles

The general kitchen areas referred to in this study included the cooking, front counter and food preparation areas. The beverage area in the Taiwan study was not included in the current study since the beverage areas in the US fast-food restaurants were either incorporated in the front counter floor area or completely outside of the kitchen area. The oven working areas in the Taiwan study were replaced with the grill areas in the current study in the USA. The grill areas in the fast-food restaurants in Taiwan were generally very small due to the small volume of grilled food served, while the oven areas in Taiwan were generally bigger. Six major working areas in the USA, including the back vat, front counter, fryer, grill, sink and walk through, were identified in each restaurant. These areas represented work areas for the majority of employees. The grill is used to cook beef patties for hamburgers. The back vat and fryer are the areas for frying chicken and french fries, respectively. The front counter is the area to take customers' orders and payments and to deliver food. The sink is used for washing cookware. The walk through area is the entrance where employees enter and exit the kitchen.

The typical flooring in these restaurant kitchens was quarry tile which has an approximate dimension of 15 by 15 cm (6 by 6 in.). The tiles in seven out of the ten restaurants visited originally had grit particles embedded on the surface, but some of the grit particles appeared to be worn. At the time of the visits, the ages of the tiles were estimated to be between 2 and 32 years with an average and standard deviation of 14 and 12.6 years, respectively.

2.3. Tile selections for friction measurements

A line of tiles in the direction of traffic through an area was measured in the selected areas in order to reflect what employees might encounter when walking through the area. This line of measurements was made at least 30 cm from the wall or the edge of the cooking equipment since employees usually do not walk very close to these landmarks.

Due to the likelihood of contamination by water and/or grease, the back vat, fryer, grill and sink were considered critical areas in the kitchen (Chang et al., 2003). The walk through areas were in a confined space which limited the number of tiles available for measurements. One tile was measured approximately every 30 cm in these five areas, which represents approximately a half step length of a human stride (Sun et al., 1996). One tile was measured approximately every 60 cm in the front counter areas which were considered less critical due to a less likelihood of contamination. Friction was measured in the area directly in front of the cooking equipment in the working areas of the back vat, fryer, grill and sink, but in the middle of the front counter and walk through areas.

2.4. Friction measurement and surface conditions

In order to avoid cross-contamination across different working areas, the same footwear pad was always used in the same working area across all the restaurants. The same operator completed the measurements in each working area using the same slipmeter in order to reduce variations due to different operators and slipmeters.

Along the line of tiles selected, friction was measured in both directions with one measurement for each direction on each tile chosen. Prior to the two friction measurements of each tile, the Neolite pads were sanded once, with 400 grit abrasive paper using the sanding protocols introduced by Chang et al. (2003).

In order to simulate actual floor conditions when washing tasks were being performed, wet measurements were conducted on the tiles in front of the sinks by applying water at the maximum thickness allowed by surface tension on the floor surface. Water was replenished in the footwear striking area throughout the measurements under the wet conditions. The surface conditions on the tiles measured were not altered except for wet testing and the removal of loose debris.

2.5. Survey of floor slipperiness

Those employees working during the lunch period on the day of the visit were invited to participate in the survey of floor slipperiness and their time for completing the survey was compensated. The protocol was approved by the Liberty Mutual Research Institute for Safety's institutional review committee for the protection of human subjects.

The participants answered the survey questions anonymously. The slipperiness survey questions were translated into English, Spanish and Portuguese. The participants had the option of completing the survey in one of these three languages. During data collection, study personnel fluent in both Spanish and Portuguese were present at each site. The participants rated the slipperiness of the same floor areas measured with the slipmeters using a four-point rating scale, with 1 as "extremely slippery" to 4 as "not slippery at all", according to their recall of experience in the kitchen during that lunch period on the day of the visit. They were also asked whether they were in these areas during that lunch period. The results of their ratings in those areas where they had not been during the lunch time were not included in the perception rating analyses.

2.6. Statistical analyses

Similar to the analyses used in the study conducted in Taiwan, a two-way analysis of variance (ANOVA) was used to determine whether restaurant and area made a significant difference in the measured friction values and perception ratings. A Duncan's multiple range test was used to examine the differences among the selected areas in the measured COF values and perception ratings in which the results from all restaurants were pooled. Similarly, the Pearson's and Spearman's correlation coefficients were calculated between the average perception rating score and measured COF for each working area across all the restaurants. The coefficients of variation (CV), obtained by dividing the standard deviation by its mean value, for friction coefficients and perception rating scores of all the areas in the restaurants were calculated. The Pearson's and Spearman's correlation coefficients between CV values of the average perception rating score and measured COF for each working area across all the restaurants were calculated. The linear regression models between the average COF measured and perception rating score for each area across all the restaurants in both studies were obtained separately and compared.

3. Results

Friction was measured on a total of 353 tiles in this experiment. The number of tiles measured per restaurant ranged from 26 to 40 with an average of 35.3. The means and standard deviations of the numbers of tiles measured in each area were 4.5 ± 0.97 (back vat), 5.2 ± 0.63 (front counter), 4.7 ± 0.82 (fryer), 7.2 ± 0.63 (grill), 8.5 ± 2.80 (sink) and 5.2 ± 0.79 (walk through).

The means and standard deviations, shown in parentheses, of the COF values measured in each area of each restaurant are shown in Table 1. For the friction measured, the results of the ANOVA indicated that both participating restaurant and evaluated area were significant factors ($p < 0.001$). Table 2 shows the means, standard deviations, and Duncan's group of the six areas in COF. The front counter areas had the highest COF value with a mean value of 0.77 which was significantly higher ($p < 0.05$) than the back vat, grill and sink. The friction coefficient in the fryer (0.73) and walk through (0.73) came in the second group. The COF values in the grill (0.69) and back vat (0.69) areas were in the third group and were significantly higher ($p < 0.05$) than in the sink area (0.28).

A total of 126 employees participated in the study for a response rate of 87.5% across all ten restaurants. The number of participants per restaurant ranged from 9 to 17 with an average of 12.6. Participants had an average of 34.5 (standard deviation of 8.6) work hours per week with a average age of 30 (ranging from 15 to 76) years, and had worked

Table 1
Means and standard deviations, shown in parentheses, of friction coefficients for the six areas in the ten restaurants

Restaurant	Back vat	Front counter	Fryer	Grill	Sink	Walk through
1	0.95 (0.038)	0.82 (0.044)	0.90 (0.038)	0.87 (0.052)	0.56 (0.068)	0.75 (0.027)
2	0.71 (0.138)	0.76 (0.171)	0.66 (0.125)	0.63 (0.085)	0.05 (0.012)	0.64 (0.135)
3	0.60 (0.114)	0.92 (0.105)	0.90 (0.179)	0.79 (0.157)	0.04 (0.024)	0.81 (0.125)
4	0.79 (0.063)	0.82 (0.063)	0.74 (0.069)	0.75 (0.043)	0.27 (0.088)	0.76 (0.037)
5	0.73 (0.032)	0.86 (0.022)	0.84 (0.023)	0.64 (0.065)	0.60 (0.070)	0.80 (0.055)
6	0.65 (0.063)	0.78 (0.017)	0.60 (0.135)	0.71 (0.104)	0.08 (0.051)	0.79 (0.052)
7	0.49 (0.111)	0.70 (0.075)	0.60 (0.040)	0.71 (0.042)	0.28 (0.106)	0.70 (0.149)
8	0.54 (0.091)	0.57 (0.084)	0.37 (0.061)	0.47 (0.111)	0.07 (0.018)	0.53 (0.074)
9	0.61 (0.097)	0.61 (0.047)	0.67 (0.083)	0.55 (0.106)	0.05 (0.036)	0.79 (0.114)
10	0.84 (0.025)	0.84 (0.053)	0.87 (0.035)	0.76 (0.035)	0.49 (0.058)	0.79 (0.079)

Table 2
Sample sizes (n), means, standard deviations and multiple comparison results for different areas for the measured COF

Area	n	Mean	Standard deviation	Duncan group[a]
Front counter	104	0.77	0.129	A
Walk through	104	0.73	0.123	A, B
Fryer	94	0.73	0.182	A, B
Back vat	90	0.69	0.147	B
Grill	144	0.69	0.136	B
Sink	170	0.28	0.233	C

[a] Different letters in Duncan group mean they were significantly different at $\alpha = 0.05$.

in their specific location an average and median of 34.5 and 17 months, respectively. Women accounted for 60% of the participants. A total of 48% of the participants identified themselves as White, 44% as Hispanic, 4% as Black and 4% as Asian.

Table 3 shows the average perception ratings of slipperiness for the lunch time, with standard deviations shown in parentheses, for each working area across all the restaurants. As mentioned previously, the results of the participants' ratings on particular areas were not included in the analyses if they were not in the areas during the lunch time on the day of the visit. Since most of the participants worked in multiple areas over the lunch period, the number of areas checked by the participants for working there during the lunch time ranged from 0 to 6, with a mean and standard deviation of 4.6 and 1.5, respectively. Conversely, the number of employees who rated a working area ranged from 3 to 15, with a mean and standard deviation of 9.37 and 2.66, respectively. The results of the two-way ANOVA indicated that both restaurant and area were significant factors in perception ratings ($p < 0.001$). Table 4 shows the means, standard deviations, and Duncan's group of the six areas in perception ratings. The mean ratings in the fryer (2.84), grill (2.84), sink (2.85) and back vat (3.02) areas showed that they were rated as the most slippery areas and the ratings were significantly ($p < 0.05$) lower than those of the front counter (3.60) and walk through (3.64) areas. The differences among the fryer, grill, sink and back vat areas and between the front counter and walk through areas were not statistically significant.

The Pearson's and Spearman's correlation coefficients between the average friction level and the average perception rating score for each working area across all the restaurants

Table 3
Means and standard deviations, shown in parentheses, of perception rating score for the lunch time on the day of the visit for the six areas in the ten restaurants

Restaurant	Back vat	Front counter	Fryer	Grill	Sink	Walk through
1	2.80 (1.10)	3.00 (1.41)	3.00 (1.00)	3.00 (1.10)	2.00 (1.00)	3.20 (1.30)
2	2.43 (1.13)	3.60 (0.52)	2.08 (1.08)	2.37 (0.92)	2.25 (0.97)	3.83 (0.39)
3	3.50 (0.67)	3.82 (0.41)	3.62 (0.65)	2.80 (1.03)	3.27 (1.03)	3.82 (0.41)
4	2.87 (0.84)	3.41 (0.54)	2.20 (1.23)	2.71 (1.11)	3.40 (0.55)	3.56 (0.53)
5	3.00 (0.93)	3.71 (0.47)	3.27 (0.65)	3.00 (0.87)	3.22 (0.67)	3.57 (0.85)
6	3.10 (0.57)	4.00 (0.00)	3.08 (0.64)	3.15 (0.69)	2.90 (0.99)	3.82 (0.60)
7	2.45 (0.82)	3.73 (0.47)	2.33 (0.78)	2.56 (0.53)	2.62 (0.92)	3.36 (0.51)
8	3.00 (0.89)	3.25 (0.46)	2.78 (0.97)	2.17 (0.75)	2.50 (1.07)	3.78 (0.67)
9	3.57 (1.13)	3.22 (1.09)	3.08 (0.76)	3.33 (1.00)	3.00 (0.78)	3.55 (0.93)
10	3.43 (0.79)	3.50 (0.71)	2.90 (0.74)	2.87 (1.13)	2.87 (0.84)	3.67 (0.50)

were 0.33 ($p = 0.01$) and 0.36 ($p = 0.005$), respectively. The relationship between the average friction coefficient and the average subjective score for each working area across all the restaurants is shown in Fig. 1. However, the Pearson's and Spearman's correlation coefficients between the CV values of the average friction level and the average perception rating score for each working area across all the restaurants did not reach a statistically significant level. The CV values for friction measurements in each working area in the USA were, on average, much lower than those obtained in Taiwan.

The relationship between the level of friction and average perception rating score in each working area, along with the comparable data from our previously published paper based on the Taiwan study (Chang et al., 2004), is graphically illustrated in Fig. 2. Linear regression models between the level of friction and perception rating score were obtained separately for the data from the USA and Taiwan (Fig. 2). The regression model for the data obtained in the USA is

$$\mathrm{PRS} = 0.728 \times \mathrm{COF} + 2.632$$

Table 4
Sample sizes (n), means, standard deviations and multiple comparison results for different areas for the subjective ratings of floor slipperiness

Area	n	Mean	Standard deviation	Duncan group[a]
Walk through	102	3.64	0.672	A
Front counter	97	3.60	0.640	A
Back vat	81	3.02	0.908	B
Sink	89	2.85	0.948	B
Fryer	108	2.84	0.949	B
Grill	85	2.84	0.924	B

[a] Different letters in Duncan group mean they were significantly different at $\alpha = 0.05$.

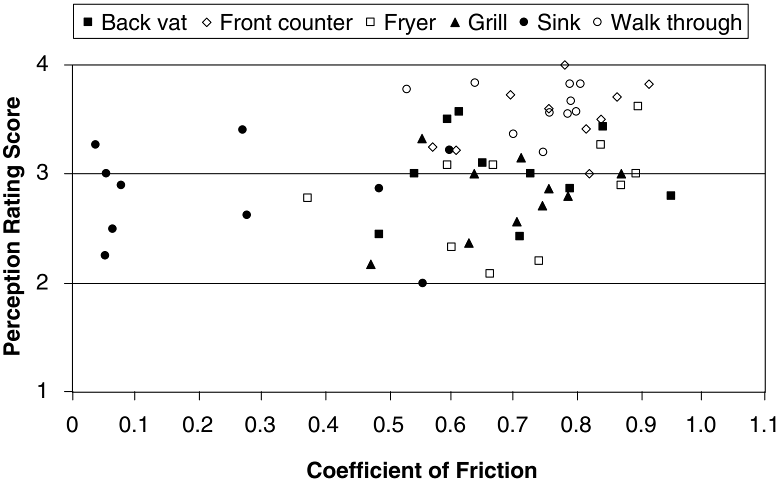

Fig. 1. Average coefficient of friction versus subjective score for each working area across ten restaurants.

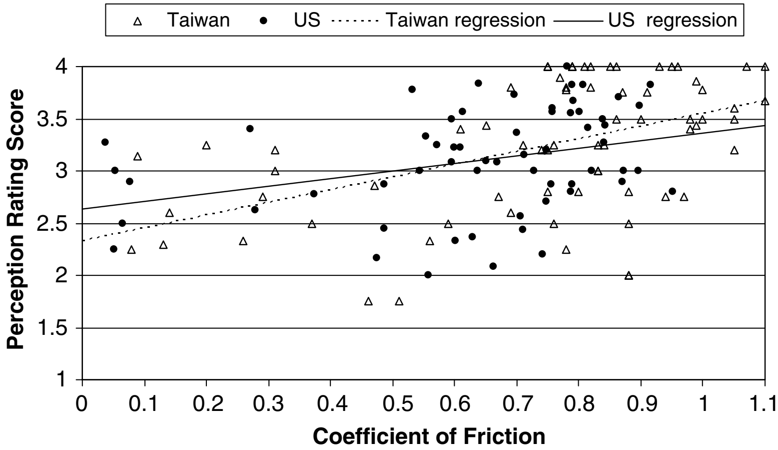

Fig. 2. A comparison of the level of friction versus average perception rating score in each working area across all the restaurants between the results collected in the USA and Taiwan along with their regression models.

where PRS is the perception rating score and COF is the level of friction coefficient. The corresponding model for the Taiwan data is

$$\mathrm{PRS} = 1.211 \times \mathrm{COF} + 2.333.$$

These two models intercept at the friction coefficient of 0.619. The regression models indicated that the participants in Taiwan tended to give a lower perception rating score than the USA counterparts when the friction coefficient was less than 0.619, and to give a higher perception rating score when the friction coefficient was more than 0.619.

4. Discussion

The results obtained in the current study show a fair degree of consistency with the results of the prior study using substantially the same design and protocol in Taiwan. This degree of replication indicates that the design approach was effective when tested in a substantially different region of the world and across a variety of languages and cultures.

Despite the consistency of results, there are several differences between the current and prior studies. Comparing the perception rating scores between participants in the USA and Taiwan, the linear regression equation for the perception rating scores and level of friction obtained in Taiwan had a somewhat greater slope than that obtained in the USA, as shown in Fig. 2. Furthermore, the Pearson's and Spearman's correlation coefficients between the averaged friction coefficients and subjective ratings in the USA were 0.33 and 0.36, respectively, which were lower than those obtained in Taiwan of 0.49 and 0.45, respectively. This indicated that the average perception rating score from the participants in the USA was less sensitive to the level of friction than that from the participants in Taiwan.

Several factors that were different between these two studies could affect the sensitivity of perception to the coefficient of friction. Cultural attitudes towards employment and risk perception could account for some of the difference in perception ratings of slipperiness. Factors that could impact the results in this regard include the cultural beliefs, languages, homogeneity (US workers were ethnically and linguistically more diverse) and ages of the working population, and common practices in the society. Another factor could be that more participants in the USA wore slip resistant shoes than in Taiwan. Among 10 restaurants visited in the USA, slip resistant shoes were mandatory in three restaurants, voluntary in four and non-existent in three at the time of the visits. The shoe requirements for the participants in Taiwan were less restrictive. The participants there were only required to wear black colored shoes to work. A greater degree of shoe sole wear was observed on the shoes worn by the participants in Taiwan. The friction level in the sink areas in both studies had an average of 0.28, while the average perception rating score for the sink areas in the USA (2.85) was slightly higher than that in Taiwan (2.70). This higher rating score in the USA could have been affected by the use of slip resistant shoes.

In addition to the potential differences in cultural attitude and slip resistant footwear use, another factor could have been the amount of water on the floors in the sink areas which could not be quantified during the study. Initial walkthrough and pilot study observations indicated that the sink area was typically wet, hence the values of wet measurements in the sink area have been reported here. Dry measurements were conducted on the same tiles in the sink areas as the wet measurements. Although the results of dry measurements in the sink areas are not reported here, the friction levels for these measurements were as high as those for the walk through areas. However, the participant perception rating scores for the sink areas were not as high as those for the walk through areas, and were near the lowest score among the areas evaluated in some restaurants. This suggests that some level of water contamination existed in the sink areas during the lunch periods. As a part of the protocol in the sink areas, the amount of water used in the wet friction measurements was the maximum amount allowed by the surface tension and it was added onto the tile surfaces by the measurement teams. This amount of water might not be the same as that in actual operations. The amount of water could affect the friction coefficient measured (Chang et al., 2001b) and perception rating scores. In fact, the friction values from the sink areas were generally lower than those from other areas evaluated, but the perception rating scores for the sink areas were not necessarily significantly lower than some other areas in the results from both Taiwan and the USA. This discrepancy in average friction coefficients and perception rating scores in the sink areas could be caused by different amounts of water during the friction measurements and during actual operations. In contrast with their counterparts in the USA, the sinks in Taiwan were used for defrosting chicken pieces in addition to washing cookware. Based on our observations, there appeared to be more water on the floors in the sink areas in the restaurants in Taiwan, probably due to a heavier usage of the areas than in the USA. Not being able to quantify the amount of water on each tile in the sink areas over the course of the lunch periods prevented us from documenting the floor conditions in these areas.

Contaminants, often present on the floors of the major food processing and cleanup areas, are likely to reduce COF. The contaminants on the floor surfaces might change with time due to factors such as additional build-up, cleaning, foot traffic and evaporation. The friction values of the tiles in the kitchens are location-dependent as well as time-dependent. The perception survey results reflected the floor conditions throughout the whole lunch period and were potentially influenced by employees' prior experience in their work areas, but the friction measurement results of the current study reveal only the friction status at the time of measurement. This could potentially reduce the correlation coefficients between the perception rating scores and measured friction coefficients.

There were several additional differences between the studies conducted in Taiwan and the USA. There were 7 working areas in each restaurant in the study conducted in Taiwan, while there were only 6 working areas in each restaurant in the USA study. There were slightly fewer tiles measured in the USA (353) over 6 working areas than in Taiwan (414) over 7 working areas. The mean COF values in the front counter and walk through areas in the USA (0.77 and 0.73, respectively) were lower than those in the same areas in Taiwan (0.90 for both), but the mean perception rating scores for these areas in the USA (3.6 and 3.64) were only slightly lower than those in Taiwan (3.72 and 3.74). The sink areas had almost the same mean COF in both studies (0.28 for both), but the mean perception rating scores for the sink areas in the USA (2.85) were on average slightly higher than those in Taiwan (2.7). All other areas appear to have similar levels of friction in both studies. There were more participants in the perception rating survey in the USA (126) than in Taiwan (56). There were small differences in the training of team members assigned to operate the slipmeters prior to data collection in both studies. Since more than half of the team members in the USA study had extensive prior experience in operating this slipmeter in both field and laboratory environments, less experienced operators did not go through as vigorous training as their counterparts in Taiwan where only one operator was an experienced user of this slipmeter. However, the less experienced operators in the US team were usually paired with an experienced operator in collecting the measurements and sought help from the experienced operators when needed. Two different Neolite samples were used in Taiwan, but six were used in the USA. The results of Chang and Matz (2001) indicated that different samples of the same materials could lead to a statistically significant difference in the measured COF. In the USA restaurants, two slipmeters were used randomly over all the selected areas, depending on the conditions and availability, but particular slipmeters were used in particular areas in Taiwan. All the participating restaurants in the USA were owned by one chain, but those in Taiwan belonged to several chains due to difficulties in recruiting restaurants in Taiwan. Therefore, the floor conditions across participating restaurants in the USA might be more consistent than those in the restaurants participating in the Taiwan study.

Most of the limitations listed in the previous study (Chang et al., 2004) are also applicable to this study. Multiple operators, Neolite samples and slipmeters were used in each restaurant, and friction in different restaurants was measured on different days. In addition to the significance of friction variations with different samples, identical pads measured at different times could lead to statistically significant differences in the measured friction coefficient (Chang, 2002). Also, friction measurements were conducted with smooth Neolite pads, but employees wore different kinds of shoes with different shoe sole materials, tread patterns and degrees of wear that could induce variations in perception and affect the correlation between perception and friction. The nature of this study conducted in a field environment limited the ability to calibrate participants' perception rating standards. Cross-contaminations, especially water in the sink area to other working areas, were not considered, since wet testing was conducted in the sink areas only. Also, accumulation of grease on the Neolite pad during repeated strikes, as reported by Chang et al. (2003), could potentially affect the results of friction measurements in these greasy areas. The Brungraber Mark II appears to have a more significant squeeze-film effect that could lead to lower COF values on liquid contaminated surfaces than other slipmeters with similar measurement characteristics (Chang et al., 2001a). This extra squeeze-film effect might cause the discrepancy that the friction values from the sink areas were generally lower than those from other areas, while the perception rating scores for the sink areas were not necessarily significantly lower than some of other areas in both studies.

5. Conclusions

The results obtained in the current study indicated that the protocols used in a field study conducted in Taiwan could be used in similar work environments in the USA with a more diverse workforce and consistent results could be obtained in the correlation between the tested objective and subjective measurements of slipperiness. The Pearson's and Spearman's correlation coefficients between the averaged friction coefficients and subjective ratings for all 60 evaluated areas across all 10 restaurants in the USA were 0.33 ($p = 0.01$) and 0.36 ($p = 0.005$), respectively. These correlation coefficients obtained in the USA were somewhat lower than those obtained in Taiwan. The amount of water on the floors in the sink areas, cultural differences and a greater use of slip resistant shoes might be some contributors to the lower correlation coefficients since the USA participants gave slightly higher perception rating scores when the friction coefficient was low in the sink areas. However, the current study confirmed the results obtained in Taiwan that the average friction coefficient and perception are in fair agreement, suggesting that both might be reasonably good indicators of slipperiness.

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References

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, 15.07, West Conshohochen, PA, American Society for Testing and Materials.

Andres, R.O., Chaffin, D.B., 1985. Ergonomic analysis of slip-resistance measurement devices. Ergonomics 28, 1065–1079.

Andres, R.O., O'Connor, D., Eng, T., 1992. A practical synthesis of biomechanical results to prevent slips and falls in the workplace. In: Kumar, S. (Ed.), Advances in Industrial Ergonomics and Safety IV: Proceedings of the Annual International Industrial Ergonomics and Safety Conference. Taylor and Francis, London, pp. 1001–1006.

Ballance, P.E., Morgan, J., Senior, D., 1985. Operational experience with a portable friction testing device in university buildings. Ergonomics 28, 1043–1054.

Chang, W.R., 2002. The effects of slip criteria and time on friction measurements. Safety Science 40, 593–611.

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

Chang, W.R., Grönqvist, G., Leclercq, S., Brungraber, R.J., Mattke, U., Strandberg, L., Thorpe, S.C., Myung, R., Makkonen, L., Courtney, T.K., 2001a. The role of friction in the measurement of slipperiness, Part 2: Survey of friction measurement devices. Ergonomics 44, 1233–1261.

Chang, W.R., Grönqvist, G., Leclercq, S., Myung, R., Makkonen, L., Strandberg, L., Brungraber, R.B., Mattke, U., Thorpe, S.C., 2001b. The role of friction in the measurement of slipperiness, Part 1: Friction mechanisms and definition of test condition. Ergonomics 44, 1217–1232.

Chang, W.R., Cotnam, J.P., Matz, S., 2003. Field evaluation of two commonly used slipmeters. Applied Ergonomics 34, 51–60.

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

Chang, W.R., Filiaggi, A., Li, K.Y., Huang, Y.H., Courtney, T.K., 2005. A field assessment of potential friction variation in a fast-food restaurant in the USA. In: Bust, P.D., McCabe, P.T. (Eds.), Contemporary Ergonomics. Taylor and Francis, London, pp. 519–523.
Cohen, H.H., Cohen, D.M., 1994. Psychophysical assessment of the perceived slipperiness of floor tile surfaces in a laboratory setting. Journal of Safety Research 25 (1), 19–26.
Courtney, T.K., Sorock, G.S., Manning, D.P., Collins, J.W., Holbein-Jenny, M.A., 2001. Occupational slip, trip, and fall-related injuries—can the contribution of slipperiness be isolated? Ergonomics 44, 1118–1137.
Grönqvist, R., Hirvonen, M., Tuusa, A., 1993. Slipperiness of the shoe-floor interface: comparison of objective and subjective assessments. Applied Ergonomics 24 (4), 258–262.
Grönqvist, R., Hirvonen, M., Tohv, A., 1999. Evaluation of three portable floor slipperiness testers. International Journal of Industrial Ergonomics 25, 85–95.
Grönqvist, R., Abeysekera, J., Gard, G., Hsiang, S.M., Leamon, T.B., Newman, D.J., Gielo-Perczak, K., Lockhart, T.E., Pai, C.Y.C., 2001. Human-centred approaches in slipperiness measurement. Ergonomics 44, 1167–1199.
Harrison, R., Malkin, F., 1983. On-site testing of shoe and floor combinations. Ergonomics 26, 101–108.
Leamon, T.B., 1992. The reduction of slip and fall injuries: Part II—the scientific basis (knowledge base) for the guide. International Journal of Industrial Ergonomics 10, 29–34.
Leamon, T.B., Murphy, P.L., 1995. Occupational slips and falls: more than a trivial problem. Ergonomics 38, 487–498.
Leclercq, S., Saulnier, H., 2002. Floor slip resistance changes in food sector workshops: prevailing role played by fouling. Safety Science 40, 659–673.
Leclercq, S., Tisserand, M., Saulnier, H., 1997. Analysis of measurements of slip resistance of soiled surfaces on site. Applied Ergonomics 28, 283–294.
Li, K.W., Chang, W.R., Leamon, T.B., Chen, C.J., 2004. Floor slipperiness measurement: friction coefficient, roughness of floors, and subjective perception under spillage conditions. Safety Science 42 (6), 547–565.
Marpet, M.I., 1996. Comparison of walkway-safety tribometers. Journal of Testing and Evaluation 24, 245–254.
Marpet, M.I., Fleischer, D.H., 1997. Comparison of walkway-safety tribometers: Part two. Journal of Testing and Evaluation 25, 115–126.
Myung, R., Smith, J.L., Leamon, T.B., 1993. Subjective assessment of floor slipperiness. International Journal of Industrial Ergonomics 11, 313–319.
Pater, R., 1985. How to reduce falling injuries. National Safety and Health News (October), 87–91.
Powers, C.M., Kulig, K., Flynn, J., Brault, J.R., 1999. Repeatability and bias of two walkway safety tribometers. Journal of Testing and Evaluation 27, 368–374.
Strandberg, L., 1985. The effect of conditions underfoot on falling and overexertion accidents. Ergonomics 28, 131–147.
Sun, J., Walters, M., Svensson, N., Lloyd, D., 1996. The influence of surface slope on human gait characteristics: a study of urban pedestrians walking on an inclined surface. Ergonomics 39, 677–692.
Swensen, E.E., Purswell, J.L., Schlegel, R.E., Stanevich, R.L., 1992. Coefficient of friction and subjective assessment of slippery work surface. Human Factors 34 (1), 67–77.