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Assessing slipperiness in fast-food restaurants in the USA using friction variation, friction level and perception rating

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Abstract

Although friction variation is speculated to be a significant contributor to slip and fall incidents, it has not been related to a measurement of slipperiness in the literature. This field study investigated the relationship among multiple friction variations, friction levels and the perception ratings of slipperiness in six major working areas of 10 fast-food restaurants in the USA. The mean perception rating score for each working area was correlated with various friction reduction variables across all the restaurants in comparison with its correlation with the mean friction coefficient of each working area. The results indicated that the absolute and relative reductions in friction over the whole working area, among 12 friction reduction variables evaluated, could have a slightly better correlation with the perception rating score ($r = 0.34$ and 0.37, respectively) than the mean friction coefficient of each working area (0.33). However, in friction measurements, more effort and time are needed to quantify friction variations than to obtain the mean friction coefficient. The results of the multiple regression model on the perception rating indicated that adding friction reduction variables into the regression model, in addition to the mean friction coefficient, did not make a significant impact on the outcomes. The results further indicated a statistically significant correlation between the mean friction coefficient and the maximum relative friction reduction over the whole area in each working area across all the restaurants evaluated ($r = 0.80$). Despite a slightly lower correlation with perception rating than the friction variation, the mean friction coefficient of an area is still a reasonably good indicator of slipperiness.

Keywords: Slip and fall incidents; Perception rating of slipperiness; Friction variation; Fast-food restaurants

1. Introduction

As a serious safety problem in work environments, slip, trip and fall incidents are 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). 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 reported by Leamon and Murphy (1995). Statistics further have shown that 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).

Slippery floors, typically caused by contaminants such as water and grease, are common in restaurant kitchens (Chang et al., 2003), and are a critical factor for falls on the same level (Chang et al., 2001b). Leamon and Murphy (1995) reported that slips and falls resulted in the most costly claims and the second-most frequent claims within the restaurant industry in the USA. Moreover, they reported that the incidence rate of falls on the same level was approximately 4.1 per 100 full-time restaurant employees over a 2-year period that resulted in an annual cost of approximately US $116 per employee.

Friction measurements between the shoe sole materials and floor surfaces are the most common method of assessing slipperiness (Chang et al., 2001b). Levels of

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coefficient of friction (COF) are typically used to assess the potential risk of slip and fall incidents that are generally assumed more likely to occur on floors with a low COF. Since people manipulate gait when aware of walking on slippery surfaces, this casts doubt on the validity of the level of COF as a lone indicator of slipperiness (Strandberg, 1985; Leamon, 1992; Grönqvist et al., 2001). Friction variation, in addition to the level of COF, can also play a role in determining slipperiness. Leclercq et al. (1997) and Chang et al. (2003) indicated that friction of the floor is highly location (tile) dependent. The potential for slip and fall incidents could be increased by local variations in friction (Strandberg, 1985; Pater, 1985; Andres et al., 1992; Grönqvist et al., 2001). Unexpectedly encountering an abrupt reduction in friction across floor surfaces without an opportunity for body posture adjustments could result in a slip and possibly a fall.

Most studies on friction measurements published in the literature were conducted in laboratories using new floor surfaces and artificial contaminants that may not represent what most employees encounter daily. Field studies of floor slipperiness using friction measurements are rarely reported in the literature even though realistic conditions of floor surfaces could be better reflected. The focuses of these studies were an evaluation of floor cleaning (Harrison and Malkin, 1983), an implementation of 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 the level of COF (Chang et al., 2004, 2006) and quantification of friction variations in fast-food restaurants (Chang et al., 2005).

The Brungraber Mark II, which is driven by gravity and known as a portable inclinable articulated strut slip tester (PIAST), is commonly used to measure friction in a field environment in the USA (Marpet, 1996; Marpet and Fleischer, 1997; Grönqvist et al., 1999; Powers et al., 1999; Chang and Matz, 2001; Chang et al., 2001a, 2003, 2004, 2005, 2006; Chang, 2002). The validity of the results obtained with this slipmeter was summarized by Chang et al. (2004). The standard deviations of the friction coefficient measured with this slipmeter on the same tiles in a fast-food environment without a sanding between consecutive friction measurements had averages of approximately 0.028 in the grill areas (mean 0.67), 0.024 by the fryer and back door (means 0.67 and 0.70, respectively) and 0.021 in the sink areas with water contamination (mean 0.26) (Chang et al., 2003).

Perception of floor slipperiness, in addition to the friction measurements, may also contribute to the assessment of slipperiness and could supplement objective measurements of slipperiness. Chang et al. (2004) summarized the literature on the correlation between the perception and objective measures of slipperiness. Myung et al. (1993) compared the subjective ranking of slipperiness with the static COF, and reported that a lower COF value usually resulted in a more slippery subjective ranking, concluding that there was an inverse relationship between the subjective ranking and measured COF. Swensen et al. (1992) correlated the measured COF with both subjective ranking and rating of surface slipperiness of steel beams with different coatings. They reported that the correlation between the measured COF and subjective rating of the beams were strong for both ironworkers ($r = 0.75$) and college students ($r = 0.90$). However, the subjective ranking of these surfaces was consistent with the measured COF for ironworkers but not for college students. Grönqvist et al. (1993) reported a significant correlation between the subjective scores of slipperiness and objective measurements such as the measured COF ($r = 0.97$, $p < 0.05$) and slip distance ($r > 0.99$, $p < 0.01$). Li et al. (2004) reported the Spearman rank correlations in the range of 0.8–0.98 between the subjective rating score for slipperiness and friction coefficient measured with Neolite in a university campus under spillage conditions. Chang et al. (2004) compared the subjective rating of slipperiness of seven major working areas in 10 fast-food restaurants in Taiwan and the level of COF measured in the same working areas. They reported that the Pearson and Spearman correlation coefficients between these two subjective and objective measurements of slipperiness were 0.49 and 0.45, respectively, with $p < 0.0001$ for both. In a subsequent study, Chang et al. (2006) applied the same protocols used by Chang et al. (2004) in Taiwan to 10 fast-food restaurants in the USA. They reported that the Pearson and Spearman correlation coefficients between the averaged friction coefficients and subjective ratings for all 60 evaluated areas across all 10 US restaurants were 0.33 ($p = 0.01$) and 0.36 ($p = 0.005$), respectively. Cultural differences, different amounts of water on the floors in the sink areas and the slip-resistant shoe program in the USA might be some of the factors that contributed to the reductions in the correlation coefficients in the USA when compared with the results obtained in Taiwan. Despite strong correlations summarized earlier, Cohen and Cohen (1994) reported a significant number of disagreements between the COF values of the tiles and subjective responses obtained by visual comparison of 23 tested tiles to a standard tile with a COF of 0.5.

Despite the potential importance of friction variations in slipperiness, no publication established a direct link between friction variation and slipperiness assessments. Friction variations within a step distance in the working areas of 10 fast-food restaurants based on the data reported by Chang et al. (2006) were quantified by Chang et al. (2005). As a continuation of the research program described in the previous papers (Chang et al., 2005, 2006), this study further explored the relationship between point-in-time friction measurements and employee reports of floor slipperiness over major working areas in fast-food restaurants in USA. The measured friction levels and friction variation in these working areas were correlated with perception ratings of slipperiness by employees. The main objective of this study was to investigate the relationship among the local friction variation, the level of friction and the perception rating score of the employees who worked in these areas to determine whether the friction variation could be a better indicator of slipperiness than the friction level.

2. Methods

Ten corporately owned restaurants of a fast-food chain in the USA participated in the study. The floor conditions during lunchtime in the kitchens of this restaurant type represent one of the most heavily contaminated situations in their daily operation due to the large volume of customers served over a short time period. Immediately after the lunch period, objective friction measurements and subjective perception ratings were conducted concurrently in each restaurant on weekdays, starting at approximately 1 p.m. with an attempt to capture lunchtime conditions as closely as possible. There was no major floor cleaning in these restaurants between the lunch period and the time when friction was measured.

2.1. Slipmeter

Friction was measured with two Brungraber Mark II slipmeters using Neolite test liners, a commonly used testing material in the USA, as footwear pads. The guidelines for operating this slipmeter were published by the American Society for Testing and Materials (ASTM) (American Society for Testing and Materials F1677-05, 2005). The details of the refined protocols used in this experiment in operating this slipmeter can be found 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. Six major working areas, 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 and included most of the highly contaminated areas along with some less-contaminated areas for comparison. 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.

Quarry tile with an approximate dimension of 15×15 cm (6×6 in) was the typical flooring in these restaurant kitchens. Of the 10 restaurants visited, the tiles in seven originally had grit particles embedded on the surface, but some of the grit particles appeared to be worn. The ages of the tiles at the time of the visits were estimated to range between 2 and 32 years with a mean and standard deviation of 14 and 12.6 years, respectively.

2.3. Tile selections for friction measurements

In order to reflect what employees might encounter when walking through the selected areas, a line of tiles through each area was measured. To represent the walking path through the area, this line of measurements in the direction of traffic was at least 30 cm from the edge of the cooking equipment or the wall since employees usually do not walk very close to these landmarks.

The back vat, fryer, grill and sink were considered critical areas in the kitchen due to the likelihood of water and/or grease contamination (Chang et al., 2003). There were limited numbers of tiles available for friction measurements in the confined space of the walk-through areas. One tile was measured approximately every 30 cm in these five areas among the six areas evaluated, representing approximately a half step length of a human stride (Sun et al., 1996). In the front counter areas, considered less critical due to a less likelihood of contamination, one tile was measured approximately every 60 cm.

The area directly in front of the kitchen equipment of the back vat, fryer, grill and sink was considered a contaminated zone, although this was not always visually apparent. The immediate region surrounding the contaminated zone was considered less contaminated and therefore the transition zone to the normal, least contaminated areas. In order to properly capture possible friction variations in transition between a contaminated and less-contaminated zone, at least two tiles along the selected line were measured outside of each end of the contaminated zone. The protocols to measure friction and to select tiles measured were applied to the whole measured area.

2.4. Friction measurement and surface conditions

Six footwear pads were used for the friction measurements in this experiment. Each footwear pad was always used in the same working area across all the restaurants in order to avoid cross contamination across different working areas. All the friction measurements in each restaurant were started as soon as the lunch period was over, and completed on the same day. To reduce variations due to different operators and slipmeters, the measurements in each working area of a restaurant were completed by one operator using the same slipmeter.

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

Wet measurements were conducted on the tiles in front of the sinks by saturating them with water at a maximum thickness allowed by surface tension on the floor surface in order to simulate actual floor conditions when washing tasks were being performed. Water was replenished in the striking area of the footwear pad throughout the measurements under the wet conditions. The surface condition was not altered except for wet testing and the removal of loose debris. Dry measurements were conducted outside of the contaminated zones of the sinks.

Two out of all 10 restaurants visited had a slip-resistant mat in their sink area. The friction property was assumed to be uniform in each direction along the line of tiles selected based on one friction measurement in that direction on each mat.

2.5. Friction variation calculations

The COF values in the same direction from two tiles 60 cm apart, representing approximately a step length of a human stride, were used to calculate friction variations that an employee might experience while walking through the working areas. Due to different distances between neighboring measured tiles, the COF values from every other measured tile were used in all the areas to calculate the friction variation except the front counter areas in which those from each pair of consecutive tiles measured were used. The absolute friction variation of a step in one direction, $\Delta\mu_a$, was obtained by subtracting the friction value of the preceding tile from that of the subsequent tile, i.e.,

$$\Delta\mu_a = \mu_s - \mu_p,$$

where μ_s is the friction coefficient of the subsequent tile and μ_p is the friction coefficient of the preceding tile. The absolute friction variation was divided by the friction value of the preceding tile to obtain the relative friction variation of the same step in the same direction, $\Delta\mu_r$, i.e.,

$$\Delta\mu_r = \Delta\mu_a/\mu_p.$$

The relative friction variation combination was excluded from the analysis if the COF value of the preceding tile was zero. A negative friction variation value represents a lower COF value on the subsequent tile than the COF value on the preceding tile in a step. Since only reductions in friction variations could potentially contribute to slip and fall incidents, only friction reductions at a step length were included in the analyses. For each type of friction reduction in each working area (absolute or relative), the average and maximum friction reductions in the contaminated zones, the average and maximum friction reductions at the transition between contaminated and less-contaminated zones if they existed and the average and maximum friction reductions in the whole working area were calculated for each working area. There were a total of 12 friction reduction variables.

2.6. Survey of perceived floor slipperiness

The research team developed a floor slipperiness survey used in this experiment to assess floor slipperiness perceived by employees (Chang et al., 2005, 2006). Those employees who worked during the lunch period on the day of the visit were invited to participate and were compensated for completing the survey. The protocol was approved by an institutional review board for the protection of human participants.

All the participants in the survey answered the survey questions anonymously. The employees had the option of completing the survey in English, Spanish or Portuguese, and study personnel fluent in each language were present at each data collection site. According to the participants' recall of experience in the kitchen during that lunch period on the day of the visit, they 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". In addition, they were asked whether they were in these areas during that lunch period. Only the results of their ratings for those areas where they had been during lunch on that day were included in the perception rating analyses.

2.7. Statistical analyses

The Pearson and Spearman correlation coefficients between each friction reduction variable calculated and the mean perception rating of each working area across all the restaurants were calculated. The Pearson and Spearman correlation coefficients between the average friction level and the average perception rating score for each working area across all the restaurants were 0.33 ($p = 0.01$) and 0.36 ($p = 0.005$), respectively (Chang et al., 2006). These correlation coefficients were used as a benchmark for comparisons with the correlation coefficients for different combinations of friction reductions.

In addition to the single regression, a multiple linear regression model was used to determine the contributions from the friction level and friction reduction to the outcomes of the perception rating score. The friction level and one of the friction reduction variables were used to develop the regression model one at a time. Those friction reductions were identified that had a level of contribution the same as or more significant than the friction level.

3. Results

A total of 126 employees participated in the study for a response rate of 87.5% across all 10 restaurants. The participants had an average of 34.5 work hours per week (standard deviation of 8.6) with a mean age of 30 (ranging from 15 to 76) years, and had worked in their specific locations for 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. The results of average perception rating score of slipperiness with its standard deviation shown in parentheses for each working area across all the restaurants are shown in Table 1.

The Pearson correlation coefficients among mean perception rating score, mean COF and friction reduction variables of each working area are shown in Table 2. Among the 12 friction reduction variables calculated, the perception rating scores have higher correlation coefficients with the maximum absolute and relative reductions in friction over the whole working area only ($r = 0.34$, $p = 0.008$; $r = 0.37$, $p = 0.004$, respectively) than with the average of friction level ($r = 0.33$, $p = 0.01$). The maximum absolute and relative reductions in friction for each working area are shown in Tables 3 and 4, respectively. The relationships between the maximum absolute and relative reductions in friction and average perception rating score over each working area are graphically illustrated in Fig. 1. Three friction reduction parameters that had the highest Pearson correlation coefficients with the level of friction for each working area as shown in Table 2 are the average relative friction reduction in the transition between contaminated and less-contaminated zones, the average relative friction reduction over the whole working area and the maximum relative friction reduction over the contaminated zone with the correlation coefficients of 0.85, 0.84 and 0.83, respectively, with $p < 0.001$. The maximum absolute and relative reductions in friction over the whole working area, which had a higher correlation coefficient

Table 1
Number of participants (n) for each restaurant, and means and standard deviations, shown in parentheses, of perception rating score for lunch time on the day of the visit for the six areas in the 10 restaurants

Restaurant	n	Back vat	Front counter	Fryer	Grill	Sink	Walk-through
1	9	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	14	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	17	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	10	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	16	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	14	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	12	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	9	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	14	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	11	3.43 (0.79)	3.50 (0.71)	2.90 (0.74)	2.87 (1.13)	2.87 (0.84)	3.67 (0.50)

Table 2
The Pearson correlation coefficients based on perception rating score, mean COF and various friction reduction variables from each working area

	MCOF	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	FR10	FR11	FR12
PRS	0.33**	0.18	0.25	0.20	0.23	0.27*	0.29*	0.34**	0.37**	0.07	0.08	0.11	0.11
MCOF	–	0.28*	0.78**	0.29**	0.83**	0.51**	0.84**	0.64**	0.80**	0.76**	0.85**	0.67**	0.77**
FR1		–	0.75**	0.94**	0.52**	0.87**	0.62**	0.55**	0.44**	0.35*	0.37*	0.32*	0.37*
FR2			–	0.72**	0.92**	0.82**	0.95**	0.74**	0.81**	0.70**	0.78**	0.63**	0.73**
FR3				–	0.58**	0.85**	0.62**	0.60**	0.51**	0.37*	0.37*	0.35*	0.39*
FR4					–	0.69**	0.93**	0.79**	0.90**	0.77**	0.86**	0.73**	0.83**
FR5						–	0.85**	0.85**	0.73**	0.72**	0.72**	0.70**	0.71**
FR6							–	0.87**	0.92**	0.87**	0.93**	0.83**	0.88**
FR7								–	0.92**	0.93**	0.91**	0.95**	0.94**
FR8									–	0.91**	0.94**	0.94**	0.98**
FR9										–	0.98**	0.94**	0.92**
FR10											–	0.92**	0.94**
FR11												–	0.97**
FR12													–

PRS: perception rating score; MCOF: mean COF; FR1: average absolute friction reduction in contaminated zone; FR2: average relative friction reduction in contaminated zone; FR3: maximum absolute friction reduction in contaminated zone; FR4: maximum relative friction reduction in contaminated zone; FR5: average absolute friction reduction over the whole working area; FR6: average relative friction reduction over the whole working area; FR7: maximum absolute friction reduction over the whole working area; FR8: maximum relative friction reduction over the whole working area; FR9: average absolute friction reduction in transition between contaminated and less-contaminated zones; FR10: average relative friction reduction in transition between contaminated and less-contaminated zones; FR11: maximum absolute friction reduction in transition between contaminated and less-contaminated zones; FR12: maximum relative friction reduction in transition between contaminated and less-contaminated zones.

*$p < 0.05$.

**$p < 0.01$.

Table 3
The maximum absolute friction reduction for each working area in the 10 restaurants

Restaurant	Back vat	Front counter	Fryer	Grill	Sink	Walk-through
1	−0.13	−0.09	−0.09	−0.15	−0.49	−0.07
2	−0.30	−0.34	−0.33	−0.28	−0.86	−0.22
3	−0.18	−0.11	−0.66	−0.56	−0.67	−0.25
4	−0.42	−0.06	−0.17	−0.25	−0.58	−0.06
5	−0.06	−0.05	−0.05	−0.18	−0.37	−0.14
6	−0.10	−0.03	−0.26	−0.30	−0.14	−0.10
7	−0.40	−0.15	−0.22	−0.17	−0.96	−0.32
8	−0.20	−0.20	−0.13	−0.23	−0.71	−0.11
9	−0.26	−0.14	−0.20	−0.22	−0.75	−0.30
10	−0.08	−0.13	−0.09	−0.16	−0.41	−0.16

Table 4
The maximum relative friction reduction for each working area in the 10 restaurants

Restaurant	Back vat	Front counter	Fryer	Grill	Sink	Walk-through
1	–0.13	–0.10	–0.10	–0.17	–0.47	–0.09
2	–0.38	–0.40	–0.40	–0.42	–0.96	–0.29
3	–0.25	–0.11	–0.60	–0.81	–1.00	–0.26
4	–0.47	–0.07	–0.22	–0.33	–0.77	–0.08
5	–0.08	–0.06	–0.06	–0.23	–0.42	–0.16
6	–0.16	–0.04	–0.40	–0.34	–0.73	–0.12
7	–0.53	–0.19	–0.35	–0.23	–0.87	–0.42
8	–0.29	–0.31	–0.29	–0.34	–0.95	–0.19
9	–0.37	–0.20	–0.27	–0.30	–1.00	–0.30
10	–0.09	–0.15	–0.10	–0.21	–0.49	–0.19

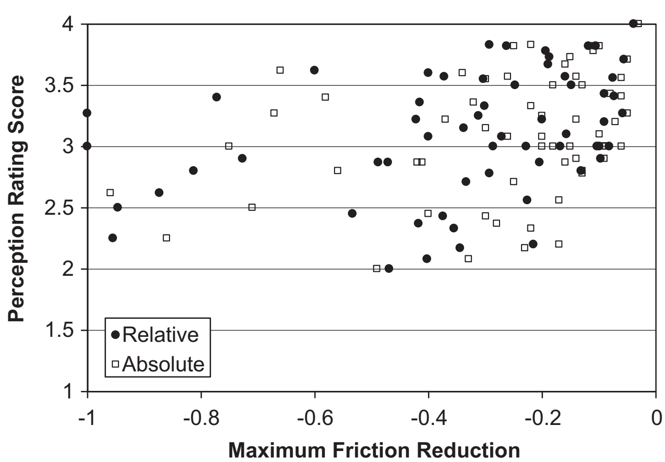

Fig. 1. The maximum absolute and relative friction reductions versus average perception rating score over each working area across all the restaurants.

with the mean perception rating, had Pearson correlation coefficients with the mean COF of 0.64 and 0.80 ($p<0.001$), respectively. The relationship between the maximum relative friction reduction over the whole working area and the mean COF for each working area is graphically illustrated in Fig. 2.

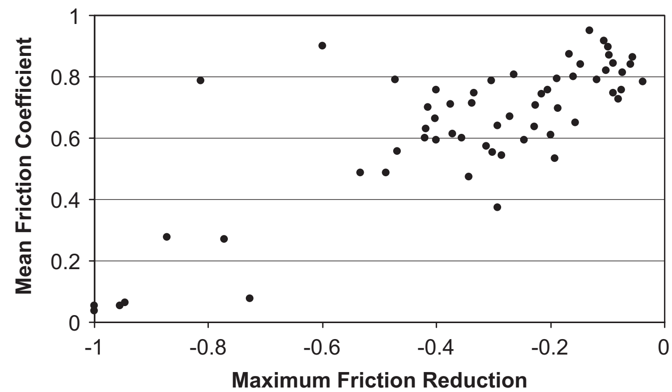

Fig. 2. The maximum relative friction reduction versus mean friction coefficient over each working area across all the restaurants.

Table 5
The results of multiple linear regression model on perception rating score

	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8
β_{MCOF}	0.303*	0.349	0.298*	0.438	0.263	0.304	0.191	0.107
β_{FR}	0.098	–0.023	0.115	–0.130	0.133	0.032	0.218	0.279
p-value	0.027	0.036	0.025	0.031	0.024	0.036	0.015	0.015
R^2	0.119	0.110	0.122	0.115	0.123	0.110	0.138	0.137
ΔR^2	0.009	0	0.012	0.005	0.013	0	0.028	0.027

See Table 2 for the definitions of MCOF and FR1 to FR8. β_{MCOF} is the β value for MCOF in multiple regression model; β_{FR} is the β value for that particular friction reduction variable in multiple regression model. For MCOF in the single regression model, $\beta = 0.331$, $R^2 = 0.110$, $p = 0.010$. ΔR^2 is defined as R^2 of multiple regression model minus R^2 of single regression model of MCOF.
*$p<0.05$.

For the Spearman correlation coefficients, the perception rating scores are better correlated with the maximum absolute and relative friction reductions over the whole working area ($\rho = 0.36$, $p = 0.008$; $\rho = 0.42$, $p = 0.001$, respectively) than with the average of friction level ($\rho = 0.36$, $p = 0.005$). Three friction reduction parameters that had the highest Spearman correlation coefficients with the level of friction for each working area are the average relative friction reduction in transition between contaminated and less-contaminated zones, the average relative friction reduction over the whole working area, and the average relative friction reduction over the contaminated zone with the correlation coefficients of 0.70, 0.69 and 0.68, respectively, with $p<0.001$.

Four friction reduction variables involving friction reductions at the transition between contaminated and less-contaminated zones were not included in the multiple linear regression model due to their low correlation coefficients with the average perception rating. The results of the multiple regression model shown in Table 5 indicated that the mean COF dominated the relationship between friction and perception when the mean COF and one of friction reduction variables were used as independent variables in six out of eight friction reduction variables evaluated. The exceptions were the maximum absolute and relative reductions in friction over the whole working areas. The R^2 values for the multiple regression models for the maximum absolute and relative friction reduction over the whole area were 0.138 and 0.137, respectively, with $p = 0.015$. However, the relationship between the perception rating score and any friction variable in both multiple regression models was not statistically significant. As a comparison, the results of single variable regression models with the perception rating score indicated that the R^2 values for the COF level, and the maximum absolute and relative reductions in friction over the whole area were 0.110 ($p = 0.010$), 0.116 ($p = 0.008$) and 0.133 ($p = 0.004$), respectively.

4. Discussion

The results obtained in this study indicate that the average perception rating score of slipperiness could have higher correlation coefficients with the maximum absolute and relative reductions in friction over the whole working area than with the average friction coefficient. They provide evidence suggesting that some variables of friction reduction might be better indicators of slipperiness than the level of measured friction as has been speculated in the literature (Strandberg, 1985; Leamon, 1992; Grönqvist et al., 2001). However, in order to properly reflect friction reductions in a working area, more extensive and systematic measurements of friction for the calculations of friction reductions are needed. In particular, the friction reductions that were better correlated with the perception rating score were those involving the maximum absolute and relative reductions in friction from the whole working area which involved measuring tiles in both the contaminated and less-contaminated zones. In order to capture these special characteristics in a working area, an extensive measurement strategy is required to cover the whole working area. More time and energy are required for friction measurements in order to obtain meaningful data for the friction reduction compared with those needed to obtain the mere level of friction. The perception rating has only a slightly higher correlation coefficient with some of the friction reduction variables evaluated than with the level of friction. Since the correlation coefficients between the level of friction and several friction reduction variables, such as the maximum relative friction reduction over the whole working area, were high with a statistical significance, it indicated that an area with a low friction coefficient also most likely had a large friction reduction. This suggests that in practical applications, where time and effort are always critical and limiting factors, a compromise might be reached using only the level of friction instead of friction reduction without sacrificing the integrity of the study. However, since the results from Chang et al. (2003, 2004, 2005, 2006) indicated significant variations among the friction measured on different tiles in the same areas, if one chooses to measure only the level of friction, it is necessary to measure friction on several tiles in the area of interest and use the average to represent the level of friction in that area.

The results of multiple regression models confirmed the results of the Pearson correlation coefficients between the perception rating score and single variables of friction measurements such as the COF level and friction reductions. The R^2 values for the single regression models of the COF level, and the maximum absolute and relative reductions in friction over the whole area were 0.110, 0.116 and 0.133, respectively. Despite the statistically significant level of multiple regression models for the maximum absolute and relative reductions in friction and the COF level with the perception rating, the statistical significance did not reach 0.05 at individual levels for either independent variable. Also, there was a significant correlation between the average COF and some friction reduction variables, among the 12 evaluated, that had a higher correlation with the average perception rating. By adding a friction reduction variable such as the maximum absolute and relative reductions in friction over the whole area to the COF level, the R^2 values of the multiple regression model only increased to 0.138 and 0.137. The increase of up to 0.03 in the R^2 values does not appear enough to justify the extra effort needed to measure friction variations in practice.

The highest significant correlation between the subjective perception rating and objective friction reductions evaluated in this study was 0.37. However, some disagreements were found as some employees rated low friction reduction areas as slippery while others rated high friction reduction areas as not slippery. These inconsistencies in friction reductions and subjective ratings could result from variations in employees' exposure to the floor conditions while walking through the measured areas. As a comparison, the mean and standard deviation, shown in parentheses, of the COF values measured in each working area evaluated, in which the COF measured from tiles in the less-contaminated zones in the critical areas were excluded from these calculations, are shown in Table 6 (Chang et al., 2006). 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. Similar situations existed in the maximum absolute and relative reductions in friction related to the perception rating scores as shown in Tables 3 and 4.

Despite the uniqueness of this study conducted in a field environment, there were several limitations. The friction reduction in one step length alone might not truly reflect the degree of slipperiness. Multiple operators, Neolite samples and slipmeters were used and only one friction measurement was performed in each direction on each tile measured in this experiment with attempts to capture the friction conditions as close to those at the lunch time as possible. Different restaurants were measured on different days. The results from Chang (2002) indicated that friction

Table 6
Means and standard deviations, shown in parentheses, of friction coefficients for the six areas in the 10 restaurants (Chang et al., 2006)

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)

measured with identical pads at different times could be statistically different. In addition, different samples could also result in a statistically significant difference in the measured friction (Chang and Matz, 2001). Furthermore, different kinds of shoes with different degrees of wear were worn by employees, but friction was measured with smooth Neolite pads. Since the perception rating could be affected by the shoe material and tread pattern on the shoe bottoms, being unable to control what employees wore certainly induced differences in perception and affected its correlation with friction. Employees' rating standards could also differ. While a calibration procedure could be used to control the base of the rating scale in a laboratory study, employees used their break time to participate in the survey in this study, and space and time were limited due to the nature of this study in a field environment. In addition, cross contaminations in different working areas, especially those involving the sink, could alter employees' perceptions of other working areas besides the sink, but wet testing was not performed in other working areas to account for this possibility. Accumulation of grease on the Neolite pad during repeated strikes when using this slipmeter, as reported by Chang et al. (2003), could potentially affect the results of friction measurements in these greasy areas. The friction measurement results of the current study may reveal the friction status only at the time of measurement, but the results of the perception survey reflected the floor conditions throughout the whole lunch period. The correlation between the employees' perception rating and various measurements of friction could be improved further by eliminating some of the limitations in the future studies.

5. Conclusions

This field study investigated the relationships among friction levels, friction variations and perception ratings of slipperiness in six major working areas of 10 fast-food restaurants in the USA that belong to the same chain. The correlations between various friction reduction variables and mean perception rating score for each working area were compared with the correlation between the mean friction coefficient and perception rating score for each working area across all the restaurants. Among the 12 friction variations quantified, the perception rating scores have a slightly better correlation with the absolute and relative reductions in friction over the whole working area ($r = 0.34$ and 0.37, respectively) than with the mean friction coefficient of each working area (0.33). However, the additional effort and time needed to quantify friction variations rather than to obtain the mean friction coefficient may not be warranted, despite slightly higher correlation coefficients for the friction variations. The results of the multiple regression model on the perception ratings indicated that adding friction reduction variables into the regression model in addition to the mean friction coefficient did not make a significant impact on the outcomes. There was a statistically significant correlation between the mean friction coefficient and the maximum relative friction reduction over the whole area in each working area across all the restaurants evaluated ($r = 0.80$). Despite a slightly lower correlation with the perception rating than with some of the friction reduction variables, in practice, the mean friction coefficient of an area is still a reasonably good indicator of slipperiness. Several tiles should be measured to obtain the average friction coefficient representing that area, considering variations among different tiles as reported in the literature.

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