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An analysis of escalator-related injuries in metro stations in China, 2013–2015

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A R T I C L E I N F O

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A B S T R A C T

In order to reduce the probability and severity of escalator-related injuries and enhance the safety of passengers, this study analyzed 950 escalator-related injuries in Guangzhou metro stations to identify the characteristics and the risk factors associated with escalator-related injuries in China. The data extracted from Management Information System of Guangzhou Metro covers the site and time of the accident, age and gender of the victims, escalator condition and injury information. The results from the statistical analysis indicated that the majority of the escalator-related injuries was caused by failing to stand firm (287 cases, 30.2%), passengers carrying out other tasks (214 cases, 22.5%), not holding the handrail (168 cases, 17.7%) and unhealthy passengers (18 cases, 9.3%). Age was associated with all factors except for need for an ambulance and the distribution law of these factors differed with age groups. Elderly passengers (aged 66 years and above) accounted for the highest proportion of all injuries (49.1%), and failing to stand firm (18.63%) was the main cause of escalator-related injuries of elderly passengers. The most common mechanism of injury for all age groups was a fall, accounting for (51.0%) injuries. Proportion of injuries caused by a fall increased with age, whereas injuries attributed to entrapment decreased. Female passengers (65.9%) were more likely to be involved escalator-related injuries than male passengers (34.1%), while male passengers were more likely to have accidents caused by unhealthy physical condition than female passengers. These results based on the analysis of current accident data can be used to help metro operation corporation develop effective injury prevention measures and document the need for continued improvement of escalator safety in metro stations.

1. Introduction

With rapid urbanization in China, metro as one of the quick, comfortable and environment-protected transportation modes is being constructed in many cities. As a result, as of September 5, 2016, up to 44 cities in China had been approved to construct metro systems, and 27 cities have already been operating metro systems. Additionally, according to recent statistics, metro network systems are expanding at a rate of 30–50 km per year in such highly populated cities as Beijing, Shanghai and Guangzhou (Zhang et al., 2016). However, as more and more new lines are brought into service, benefits of road traffic relief and environmental pollution reduction are not the only things that are coming out, but also new challenges and demands for reliable and safe metro operation also become important.

The tracks and stations of the metro system consist of underground, at grade, and elevated sections. Passengers enter or leave a metro station either through stairs, escalators, or elevators. Escalators are usually their favorite choice (Chi et al., 2006). A heavy-duty escalator is designed specifically for transit system usage and substantially different from commercial units in the design of truss, machine, step chain, step chain tensioning device, steps, brake, and other components/equipment (see Table 1). The rated speed of a heavy-duty escalator is 30% ~ 50% higher than a commercial escalator to transport more passengers. Although the safety factor of a heavy-duty escalator is higher than a commercial escalator, the large passenger flow and the high rated speed of heavy-duty escalators in metro stations may lead to more risks.

As escalators are ubiquitous, it is, however, not surprising that they have also attracted negative attention as an accident prone location. In the United States, about 10,000 escalator-related injuries requiring emergency department (ED) treatment were reported annually (Schminke et al., 2013). In China, according to General Administration of Quality Supervision Inspection and Quarantine (AQSIQ) statistics, escalator-related injuries have consistently been top ranked in special

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Table 1
Difference between commercial escalator and heavy-duty escalator.

Characteristic	Commercial escalator	Heavy-duty escalator
Motor power	low	high
No-load braking distance (m)	0.2–1	0.3–1.3
Motor brake	1	2
Wainscot	Glass	Stainless steel
Load condition	In any three hours, at least half an hour with 100% rated load	In any three hours, at least one hour with 100% rated load
Life	No rules	40 years
Escalator rated speed (m/s)	0.5	0.65–0.75
Safety factors	5	8

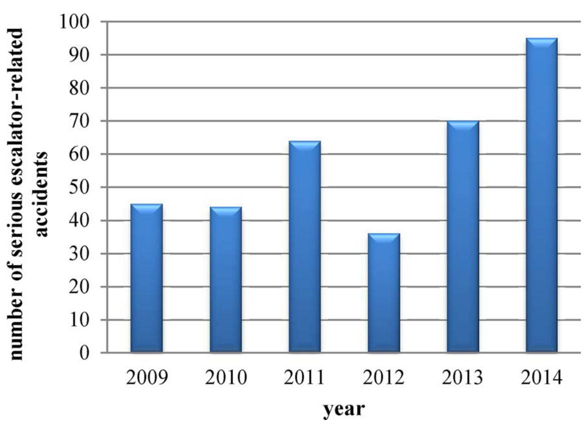

Fig. 1. Trend of serious escalator-related injuries in China, 2009–2014.

equipment accidents, while the number of serious accidents and deaths arising from those accidents had increased greatly over the past years (Fig. 1). Several deadly accidents happened in metro stations. For example, the escalator at the Beijing Zoo station on Subway Line No. 4 suddenly failed and went in the reverse direction at 9:36 a.m. on July 5, 2011, causing one death and nearly 28 people injured, with two of them severely injured. This accident not only raised the awareness among the public as well as the government on the security, maintenance and operation of escalators, but also reminded scholars in the research community to determine the characteristics and the contributing factors of escalator-related injuries.

Despite the popularity of the use of escalators, there were only few studies on the characteristics of escalator injuries. Platt et al. (1997) reviewed escalator-related injuries in children and found that young age, inadequate adult supervision, improper activity while riding on the escalator, and escalator-related mechanical problems all increased the risk of injury. Mcgeehan et al. (2006) evaluated escalator-related injuries among US children between 1990 and 2002. Using the National Electronic Injury Surveillance System (NEISS) database, McGeehan identified approximately 2000 children who sought medical attention for an escalator-related injury each year. Among children, falls and entrapments while traveling on an escalator were the leading causes of injury with a substantial number of injuries occurring to the head and distal extremities. Chi et al. (2006) studied accident patterns and high risk groups through in-depth analysis of 194 escalator riding accidents in 2000 at Taipei high capacity Metro Rapid Transit stations. Their study reported that the majority of escalator injuries were caused by passengers trying to perform other tasks while riding, failing to stand firm, not holding the handrail, or riders who were struck by other passengers. Based on data from the National Electronic Injury Surveillance System of the U.S. Consumer Product Safety Commission, O'Neil et al. (2008) analyzed escalator-related injuries among adults age 65 years and older in the U.S. between 1991 and 2005. They found that escalator-related injuries occurred infrequently but may result in significant trauma, and that these injuries were often associated with a slip, trip or fall. Lee et al. (2010) conducted a prospective survey to identify the number and nature of escalator-related injuries from May 2004 to December 2008. The analysis results showed that subway stations were the most frequent place of occurrence and the population aged 65 years old or older was the highest risk group. In particular, walking on a moving escalator was the main cause of injury for people under 65 years of age. Schminke et al. (2013) identified 173 patients > 16 years with 285 discrete escalator-related injuries and found that escalator accidents can result in severe trauma. Besides, the authors of this study also suggested that alcohol intoxication and age were significant risk factors in escalator-related injuries and might be possible targets for preventive measures. Howland et al. (2012) investigated older adult falls at a metropolitan airport to determine fall incidence, identified potential causes of these falls, and suggested opportunities for mitigation. Filippone et al. (2012) discussed the law regarding accident reconstruction involving escalators and elevators. Based on different risk management stages, Wang et al. (2015) proposed a related suitable risk analysis models for the escalator overturned accident. Wan et al. (2015) explored the classification and effects of passenger behaviors and their relations to metro incident involvement, and found that passengers usually ran along or against the operating escalator to save time. Chen and Xian (2016) analyzed 609 escalator-related injuries against preschoolers in Guangdong Province, China. They found that mal-dressing was the main direct cause to escalator-related injuries among all victims including slippers, any dress or backpack with cord. Other causes included playing with the rolling belt, too long hair or skirt, tread for power cut or other reasons.

To date, most of the studies examining escalator-related injuries had either been case studies or focused on children and older adults. Similarly, although Chi et al. (2006) studied escalator-related injuries for all ages, they only considered the high capacity metro stations. In fact, escalator-related injury is a common occurrence, whether all age groups or stations with different capacity are taken into consideration. For different research subjects, their hazard patterns will be different. Therefore, it is necessary to perform a comprehensive statistical analysis on escalator-related injuries to identify the characteristics and the risk factors associated with escalator-related injuries.

In order to reduce the probability and severity of escalator-related injuries and evaluate the effectiveness of proposed countermeasures and safety rules, this study analyzed 950 escalator-related injuries in Guangzhou metro stations in China to understand the characteristics of escalator-related injuries and identify risk factors in such accidents. Thus, results based on the analysis of current accident data can be used to develop effective injury prevention measures and document the need for continued improvement of escalator safety in metro stations.

2. Methods

2.1. Data source

Study data regarding escalator-related injuries were obtained from the Guangzhou Metro Corporation (GMC) for the years 2013–2015. Guangzhou Metro is one of the most representative metro systems in China. It consists of 10 lines and 167 stations. It also ranks third in China by annual ridership after Beijing and Shanghai, with 2.4 billion rides delivered in 2015. However, because of the huge passenger flow, passenger injury accidents happen from time to time in the metro stations. According to the location of the accident, escalator-related injuries account for 67% of all the passenger injury accidents, as shown in Fig. 2.

From 2013–2015, 950 escalator-related injuries of 6.67 billion trips took place during escalator rides in the Guangzhou metro stations. With the increase of passengers, 950 escalator-related injuries have increased

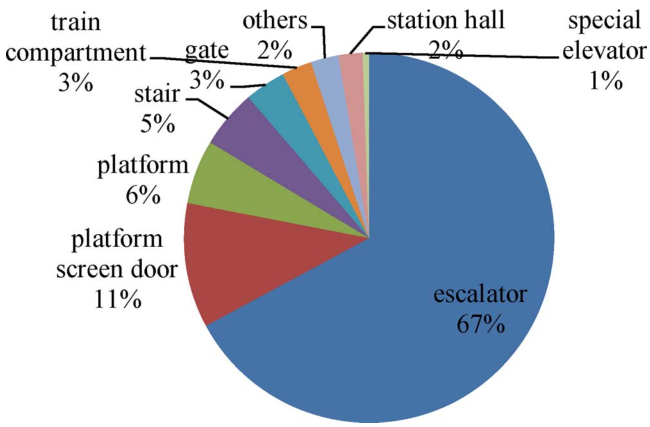

Fig. 2. Distribution of passenger injury accidents by the location of the accident.

Table 2
Overview of the injuries in Guangzhou Metro.

Indicator			
Year	Passenger flow per year (billion)	Total injuries	Escalator-related injuries
2013	1.99	418	291
2014	2.28	477	314
2015	2.40	520	345

year by year, as shown in Table 2. Those not directly related to escalators were removed from the database, for example those involving either stairs or elevators in metro stations. Besides, only the injuries required medical attention were considered in this study. The significant number of Escalator-related injuries caught the attention of the Guangzhou Metro Corporation, which wrote up a case report for each accident and recorded in the Management Information System (MIS). Each sample extracted from MIS covers the site and time of the accident, age and gender of the victims, traveling direction of the escalator, number of involved people, major causes, injured body region, whether an ambulance was needed, and any other factors which are judged to be relevant. As a consequence, factors considered in this study include passengers, environments, and injuries. In addition, prior to the analysis of escalator-related injuries, escalator safety rules were designed and put on huge paper warning signs (Fig. 3) located at escalator entry points to remind passengers of the following:

- Those who are incapable of taking the escalator alone should be accompanied by their guardians or use special elevator or staircase.
- Before taking the escalator, please confirm the traffic direction. Reverse walking on the escalator is prohibited. Keep your balance when boarding or leaving the escalator.
- Please face the traffic direction, stand on the same step and hold the handrail.
- Do not lean against the side walls of the escalator to avoid stumbling. Do not sit on the tread or stretch your head or hand out of handrail.
- Please keep your clothing or shoelaces away from the escalator tread and side shield, in case they may be entangled in the escalator gap.
- Do not place your handbag or items on the handrail. Those carrying heavy or large luggage or any items that may damage the equipment are not allowed to take the escalator.
- In case of emergency, the emergency switch can be pressed to stop the escalator. Pressing on the emergency switch under normal conditions is prohibited.
- Handcarts and baby carriages are prohibited on the escalator. Being barefoot is not allowed when taking the escalator. Do not wear “Crocs” when taking the escalator.
- No chasing or shouting. Do not crowd on the same top.
- Do not walk onto any escalator which is under maintenance or out of service.

Besides, the same information has been broadcasted in the stations to remind passengers who cannot or may not bother to read the warning signs in all Metro stations.

2.2. Variables

2.2.1. Passenger factor

Passenger’ age and gender are considered as potential risk factors in the study. According to the new standard of age groups in China, the factor, passenger age in years, is divided into five groups: ≤6, 7–17, 18–40, 41–65, and ≥66 (Zhang, 2010; Liao, 2015; Qin et al., 2015). Traveling alone or with company is also regarded as a passenger factor.

2.2.2. Environmental factor

There are three environmental factors. Time is classified into five groups in accordance with working time pattern and peoples’ lifestyle in Guangzhou: operation opening time–07:29, 07:30-09:29 (morning rush hours), 09:30-17:29 (working h), 17:30-19:59 (afternoon rush hours), 19:30- operation closing time. Traveling direction of escalators is apparently classified into two categories: upward and downward. Long escalator in Guangzhou Metro is defined as an escalator of more than or equal to 12 m in vertical hoisting height.

Fig. 3. Escalator safety rules in Guangzhou Metro.

Table 3
Frequency distribution of escalator-related injuries.

Factor	Category	Frequency	%
Gender	Male	324	34.1
	Female	626	65.9
Age(year)	0–6	56	5.9
	7–17	16	1.7
	18–40	191	20.1
	41–65	221	23.3
	≧66	466	49.1
With or without company	Without company	347	36.5
	With company	603	63.5
Time of accident	operation opening time–07:29	24	2.5
	7:30–9:29	79	8.3
	9:30–17:29	611	64.3
	17:30–19:29	87	9.2
	19:30 – operation closing time	149	15.7
Travelling direction	Upward	821	86.4
	Downward	129	13.6
Long escalator or not	Yes	192	20.2
	No	756	79.8
Hazard pattern	Falls	865	91.1
	Entrapment	29	3.1
	Injuries caused by falling objects	38	4.0
	Others including unclassified and unknown	18	1.9
Major cause	Failing to stand firm	287	30.2
	Carrying out other tasks	214	22.5
	Other passenger’s movement	168	17.7
	Not holding the handrail	110	11.6
	Unhealthy passengers	50	5.3
	Carelessness	34	3.6
	Emergency stop or shake	24	2.5
	Contacting with sides and comb boards	13	1.4
	Rushing for trains	8	0.8
	Wrong direction	7	0.7
	Others	35	3.7
Injured body region	Multiple body region	258	27.2
	Head and neck	204	21.5
	Lower extremities	185	19.5
	Upper extremities	155	16.3
	Trunk	93	9.8
	Unidentified and unknown	55	5.8
Need an ambulance	Yes	303	31.9
	No	647	68.1

2.2.3. Injurious factor

The injured body regions were grouped into five categories during study analysis: (1) multiple body regions, (2) head and neck, (3) lower extremity, (4) upper extremity, trunk and (5) other. The causes of injury categories included (1) carrying out other tasks, (2) failing to stand firm, (3) not holding the handrail, (4) other passenger’s movement, (5) emergency stop or shake, (6) contacting with sides and comb boards, (7) unhealthy passengers, (8) carelessness, (9) rush for trains, (10) wrong direction and (11) other. These major causes of accidents generate three hazard patterns: falls, entrapment, and injuries caused by falling objects. In addition, injured passengers may need an ambulance, so whether an ambulance is needed is also perceived as an injurious factor.

In conclusion, the description and categories of these variables are summarized in Table 3. The table also shows the proportional distribution of variables in the different categories.

2.3. Data analysis

Cramér's V coefficient of the contingency table was applied to evaluate the significant association between any two factors with multiple categories, e.g., the major cause of accident and the injured body region. It reflects the strength of the association in a contingency table (Agresti, 1996; Fleiss, 1981; Stuart and Ord, 1994), giving a value between 0 and +1 (inclusive). It is based on Pearson's chi-squared statistic and was published by Harald Cramér in 1946. Statistical significance of group comparisons was tested using Chi-square test or Fisher's exact test analyses. Fisher's exact test is a statistical significance test used in the analysis of contingency tables (Fisher, 1922). If there is one or more cells have an expected frequency less than 5, the significance calculation for Cramer’s V (and phi) will be invalid. This occurs if some of the number of columns and rows in the cross-table are small. Therefore, the Fisher test is usually only applied to relatively small samples. For large samples, results based on chi-square are relatively good (powerful). Data analysis was performed using SPSS 22.0 for Windows (SPSS Inc., Chicago, Illinois, USA) and $p \le 0.05$ was considered as statistically significant.

Let a sample of size n of the simultaneously distributed variables A and B for $i = 1, \ldots, r; j = 1, \ldots, k$ be given by the frequencies n_{ij} = number of times the value (A_i, B_j) were observed.

The chi-squared statistic then is:

$$\chi^2 = \sum_{i,j} \frac{\left(n_{ij} - \frac{n_{i.}n_{.j}}{n}\right)^2}{\frac{n_{i.}n_{.j}}{n}} \tag{1}$$

Cramér’s V is computed by taking the square root of the chi-squared statistic divided by the sample size and the minimum dimension minus 1:

$$V = \sqrt{\frac{\varphi^2}{\min(k-1, r-1)}} = \sqrt{\frac{\chi^2/n}{\min(k-1, r-1)}} \tag{2}$$

where: φ^2 is the phi coefficient. χ^2 is derived from Pearson's chi-squared test. n is the grand total of observations. k is the number of columns and r is the number of rows. In the case of a 2 × 2 contingency table, Cramér's V is equal to the Phi coefficient.

In most statistical textbooks (Williams, 1984; Cohens, 1988; Taylor, 1990; Surhone et al., 2010), correlations with coefficients of $> |0.7|$ are strong, the ones with coefficients of $|0.5| - |0.7|$ are medium, and the ones with coefficients of $< |0.5|$ are weak. It should be noted that for some research these conventions do not make much sense. The interpretation of a correlation coefficient depends on the context and purposes. A correlation of 0.7 may be very low if one is verifying a physical law using high-quality instruments, but may be regarded as very high in the social sciences where there may be a greater contribution from complicating factors. For example, in Sociocultural Anthropology in general, most important sociocultural variables seem to be determined by a considerable number of factors. Traffic accident analysis is similar. Rarely does it appear to be possible to single out X determining Y by more than 50% (which would correspond to correlation of $>$ 0.7 level). In this context, White and Korotayev (2003) proposed the typology of strength of correlations that takes into account the types of correlation and data, as shown in Table 4 below. In their opinion, any X determining Y by 25–50% should be considered a

Table 4
Strength of correlations.

Correlation coefficient	Strong Spearman’s rho, Tau-b and c, Phi, Pearson’s r, Somer’s d (symmetric)	Medium Predictors: Somer’s d	WeakPredictors: Gamma
$\|1.0\|$	determinate	strong	medium
>0.7	very strong	medium	weak
$\|0.5\| - \|0.7\|$	strong	weak	quite weak[a]
$\|0.3\| - \|0.5\|$	medium	quite weak[a]	very weak
$\|0.2\| - \|0.3\|$	weak[a]	very weak	negligible
$\|0.1\| - \|0.2\|$	very weak	extremely weak	negligible
$\|<0.1\|$	extremely weak	negligible	negligible

[a] in cross-cultural research these may be still considered strong, if significant.

Table 5
Association between any two factors using Cramer's V analysis.

Contributing factors	Gender	Age	With or without company	Travelling direction	Long escalator or not	Time of accident	Hazard pattern	Major cause	Injured body region
Age	0.161 (0.000)[++]								
With or without company	0.104 (0.001)[++]	0.232 (0.000)[++]							
Travelling direction	0.013 (0.767)	0.154 (0.000)[++]	0.165 (0.000)[++]						
Long escalator or not	0.02 (0.515)	0.130 (0.003)[++]	0.041 (0.209)	0.017 (0.638)					
Time of accident	0.087 (0.126)	0.093 (0.010)[a,++]	0.095 (0.077)	0.146 (0.000)[++]	0.085 (0.141)				
Hazard pattern	0.070 (0.169)[a]	0.226 (0.000)[a,++]	0.151 (0.000)[a,++]	**0.200** (0.000)[a,++]	0.102 (0.015)[a,+]	0.055 (0.684)[a]			
Major cause	0.194 (0.000)[++]	**0.236** (0.000)[a,++]	**0.201** (0.000)[a,++]	**0.200** (0.000)[a,++]	0.153 (0.016)[+]	0.169 (0.000)[a,++]	**0.317** (0.000)[a,++]		
Injured body region	0.144 (0.001)[++]	0.178 (0.000)[a,++]	0.071 (0.446)	0.131 (0.007)[a,++]	0.092 (0.150)	0.081 (0.208)	0.139 (0.000)[a,++]	0.156 (0.000)[a,++]	
Need an ambulance	0.035 (0.303)	0.089 (0.112)	0.092 (0.005)[++]	0.019 (0.611)	0.087 (0.009)[++]	0.040 (0.826)	0.040 (0.731)[a]	0.127 (0.113)	**0.205** (0.000)[++]

In each cell, the two numbers give the Cramer's V value and significance level, respectively.
[a] Fisher's exact test is used instead of Cramer's V.
[+] Significant at 0.05.
[++] Significant at 0.01.

rather strong factor. Factors determining 10–25% of variation in a dependent variable should be rather considered as moderately strong. Therefore, in traffic accident analysis, correlations of 0.2–0.3 level, or possibly even weaker if significant should not be ignored.

3. Results

3.1. Frequency distribution

The frequency distribution of the 950 accidents for each of the coded categories is shown in Table 1. Gender is an important factor affecting passenger injuries. According to statistics, the ratio of male to female passengers is 1.2–1, which is roughly the same ratio of men to women in Guangzhou (Luo et al., 2012). Therefore, it was obvious that female victims were involved in a greater proportion (65.9%) of the escalator related accidents. This finding is in line with the findings in other studies mentioned above (Chi et al., 2006; O'Neil et al., 2008). Approximately, 49.1% of all escalator-related injuries were seen in elderly passengers (aged 66 years and above). This is probably due to the gradual decline of mental and physical capacities found among the aging (Charness, 1985). Besides, according to the statistical analysis of Woolley (1989), elderly women experience significantly more falls than elderly men, whereas women exhibit rates from 1.5 to 5 times higher than men. Passengers were more likely to be involved in escalator riding accidents when they had companions (63.5%).

Our study indicated that the vast majority of escalator-related injuries happened during work hours (64.3%). It implies that most of the escalator-related injuries are not caused by large passenger flow. Comparing with the percentage of the long escalators (5.8%) in all escalators, the proportion of the long escalator involved injuries (20.2%) in all escalator-related injuries were much higher. This indicates that long escalators may be a potential risk factor. Most accidents occurred on escalators traveling upward (86.4%) simply because the majority of the escalators in Guangzhou Metro are going upward.

Of all the hazard patterns in this study, the majority (91.1%) were the result of falls while entrapment and injuries caused by falling objects only accounted for 7.1% of all accidents in total. This proportion is different from the distribution of hazard patterns in the United States. According to the statistics of Armstrong (1996), 75% of hospital treated injuries were due to falls and another 20% occurred when hands, feet, or shoes were trapped in escalators. This situation is probably due to a much stricter escalator safety rules and installation standard adopted for Guangzhou metro stations. According to escalator safety rules, passengers should keep their clothing or shoelaces away from the escalator tread and side shield, in case they may be entangled in the escalator gap. Even "Crocs" is not allowed to be worn when taking the escalator. In order to protect children, all escalators in the Guangzhou metro stations are brush-guarded and pre-checked and the horizontal clearance between the escalator step and fixed side skirt shall not exceed 4 mm at either side, or 7 mm for the sum of clearances measured at both sides at two directly opposite points.

By assigning one primary cause for each accident, failing to stand firm (30.2%) accounts for the largest share of accidents. Almost 22.5% of accidents occurred while carrying out other tasks. The next most frequent causes were being struck by other passengers (17.7%), not holding the handrail (11.6%), and unhealthy passengers (5.6%). Approximately four percent of injuries were associated with carelessness. Another 2.5% were due to emergency stop or shaking of escalator. Thus, most of injuries were caused by passenger errors, only 2.5% of all injuries were resulted from mechanical problems with the escalator. Out of 214 cases who were carrying out other tasks, 148 passengers were carrying luggage, 39 were looking after their babies or child passengers, and 12 passengers were pushing handcarts or baby carriages, while 24 passengers out of the unhealthy passengers were under the influence of alcohol. The significance of carrying luggage was also evidenced in Cohen and Compton's (1982) analysis that thirteen percent of 3270 slip and fall injuries happened when the worker was carrying an object.

Statistics on injured body regions indicated that the multiple body regions (27.2%) and the head and neck (21.5%) were the most frequently injured body regions, while trunk was the least frequently injured body regions (9.8%). Lower extremities (19.5%) and upper extremities (16.3%) also accounted for a considerable proportion of all escalator-related injuries. There are still 5.8% escalator-related injuries that injured body regions are unidentified and unknown. For escalator-related injuries, an ambulance was needed about one third of the time (31.9%).

3.2. Significant association between different factors

Associations among all contributing factors were revealed by the Cramer's V analysis as illustrated in Table 5. Age and major cause were associated with all factors except for need for an ambulance, and half of their Cramer's V value were greater than 0.2. As mentioned in section 2.3, the association between age/major cause and other factors should be pay attention to. Hazard pattern was associated with all factors except for gender, time of accident, and need for an ambulance, while travelling direction was related to all factors except for gender, long escalator and need for an ambulance. Injured body region and with or without company were both associated with gender, age, travelling direction, hazard pattern, major cause and need for an ambulance, however, these two factors were not-related with each other. Long escalator was only associated with age, hazard pattern, major cause and need for an ambulance, while need for an ambulance was only related to with or without company, long escalator and injured body region.

4. Discussion

4.1. Associations between levels of factors

To further analyze significant associations between different contributing factors, the proportion of different levels of factors in contingency table should be analyzed. Taking association with other factors and strength of correlations into account, age and major cause are the most influential factors and the distribution of these two factors are shown in Tables 6 and 7, respectively. Moreover, according to the correlation coefficients, time of accident was almost irrelevant to age. Thus, it was not considered in further study of association between age and time of accident.

The association between age and gender indicated that passengers aged 66 years and above (male, 18.00%; female, 31.05%) and female passengers aged 39–65yrs (16.92%) had a greater tendency to be involved in escalator-related injuries than their gender counterpart (Table 6). The ratio of female involved escalator-related injuries in each age group was showed in Fig. 4. Female passengers aged 18–39 years and 40–65 years were more likely to be involved in escalator-related injuries. One possible reason was that women aged 18–65 years preferred to wear highheeled shoes which may be a potential cause of escalator-related injuries.

Unlike other age groups, passengers aged 18–39 years were more likely to be involved in escalator-related injuries when they are without company. Associations between age and traveling direction demonstrated that in these injured cases, elderly passengers (aged 66 years and above) were more likely to take escalators traveling upward.

In order to reveal the correlation between age and long escalator, the ratio of long escalator-related injuries to injuries by age group was calculated (refer to Fig. 5). Passengers aged 7–17 years and 18–39 years were more likely to be involved in long escalator-related injuries. One possible reason is that these younger passengers are less patient than middle-aged and older adults, and may be more likely to walk on a long escalator to save time.

The most frequent hazard pattern was a fall, accounting for 91.1% of all injuries and elderly passengers (aged 66 years and above) were more likely to fall at an escalator, accounting for 46.84% of all injuries. When looking at the proportion of different hazard patterns by age group, there was a consistent increase with age in the proportion of injuries that were caused by falls (Fig. 6). On the contrary, there was a consistent decrease in the proportion of injuries that were attributed to entrapment by age group. Passengers aged 6 years and above accounted for 51.7% (15 of 29) of all entrapment injuries, which illustrated that younger children were easier to be entrapped in the space between the escalator step and the sidewall, especially when there was a wide gap. Moreover, it was surprising to find that passengers aged 18–39 years were more likely to be injured by falling objects (21 of 38).

Multiple body regions were the most frequently injured body region overall (27.2%) for all age groups, with the exception of children who were younger than 7 years (Table 6). Injuries to the head and neck accounted for 21.5% of injuries overall and 57.4% of injuries happened on the passengers aged 66 years and above. Approximately thirty-six percent of all injuries were to the extremities (including lower and upper extremities); however, these two kinds of injuries occurred most frequently among passengers who were younger than 7 years, accounting for 48.2% of injuries in this age group.

The associations between age and major cause of accident indicated that children under the age of 7 yrs (20 of 56 in this age group) were often injured by carrying out other tasks. This is mainly because some passengers push the baby carriage while riding an escalator and the baby carriage is very easy to be caught in an escalator. Although handcarts and baby carriages are prohibited on the escalator in Guangzhou metro stations, some passengers still don't follow the rules leading to this situation.

For elder passengers (aged 66 yrs and above), failing to stand firm (18.63%) was the main cause of escalator-related injuries. Similar conclusion that elderly passengers are more likely to have accidents caused by failing to stand firm was also reported in Buck and Coleman's (1985) study, indicating that injury rate has a significant rising trend

Table 6
Comparison of factors relating to escalator injuries in age groups.

Contributing factors		Age Group (years)									
		0–6		7–17		18–39		40–65		≥66	
Gender	Male	32	3.37%	8	0.84%	53	5.58%	60	6.31%	171	18.00%
	Female	24	2.53%	8	0.84%	138	14.53%	161	16.92%	295	31.05%
With or without company	Without company	2	0.21%	2	0.21%	100	10.53%	80	8.42%	163	17.16%
	With company	54	5.68%	14	1.47%	91	9.58%	141	14.84%	303	31.89%
Travelling direction	Up	46	4.84%	10	1.05%	151	15.89%	198	20.84%	406	42.74%
	Down	10	1.05%	6	0.63%	40	4.21%	23	2.42%	50	5.26%
Long escalator or not	Yes	5	0.53%	6	0.63%	49	5.16%	50	5.26%	82	8.63%
	No	51	5.37%	10	1.05%	142	14.95%	171	18.00%	384	40.42%
Hazard pattern	Falls	32	3.26%	10	1.05%	165	17.37%	213	22.42%	445	46.84%
	Entrapment	15	2.00%	5	0.53%	3	0.32%	2	0.21%	4	0.42%
	Injuries caused by falling objects	5	0.42%	1	0.11%	21	2.32%	5	0.53%	6	0.63%
Injured body region	Multiple body regions	2	0.21%	8	0.84%	45	4.74%	67	7.05%	136	14.32%
	Head and neck	23	2.42%	0	0.00%	29	3.05%	35	3.68%	117	12.32%
	Lower extremities	13	1.37%	4	0.42%	54	5.68%	51	5.37%	63	6.63%
	Upper extremities	14	1.47%	2	0.21%	33	3.47%	37	3.89%	69	7.26%
	Trunk	2	0.21%	2	0.21%	19	2.00%	19	2.00%	51	5.37%

In each cell, the two numbers give number of cases and the percentage in all injuries, respectively. Cases with unknown hazard pattern and injured body region were not listed.

Table 7
Comparison of factors relating to escalator injuries in major accident cause's groups.

Contributing factors		Major cause									
		Failing to stand firm		Carrying out other tasks		Other passenger's movement		Not holding the handrail		Unhealthy passengers	
Gender	Male	92	9.68%	75	7.89%	43	4.53%	36	3.79%	35	3.68%
	Female	195	20.53%	139	14.63%	125	13.16%	74	7.79%	15	1.58%
Age (years)	0 – 6	10	1.47%	20	2.11%	5	0.53%	6	0.63%	0	0.00%
	7–17	5	0.11%	1	0.11%	2	0.21%	3	0.32%	1	0.11%
	18–39	37	3.89%	44	4.63%	50	5.26%	16	1.68%	23	2.42%
	40–65	58	6.11%	65	6.84%	47	4.95%	17	1.79%	8	0.84%
	≧66	177	18.63%	84	8.84%	64	6.74%	68	7.16%	18	1.89%
With or without company	Without company	116	12.21%	82	8.63%	50	5.26%	28	2.95%	32	3.37%
	With company	171	18.00%	132	13.89%	118	12.42%	82	8.63%	18	1.89%
Travelling direction	Up	255	26.84%	194	20.42%	145	15.26%	96	10.11%	41	4.32%
	Down	32	3.37%	20	2.11%	23	2.42%	14	14.74%	9	0.95%
Long escalator or not	Yes	44	4.63%	46	4.84%	52	5.47%	17	1.79%	8	0.84%
	No	243	25.58%	168	17.68%	116	12.21%	93	9.79%	42	4.42%
Time of accident	Operation opening time–07:29	6	0.63%	8	0.84%	2	0.21%	5	0.52%	1	0.11%
	7:30 ~ 9:29	22	2.32%	17	1.79%	12	1.26%	10	1.05%	4	0.42%
	9:30 ~ 17:29	209	22.00%	141	14.84%	105	11.05%	70	7.74%	21	0.22%
	17:30 ~ 19:29	25	2.63%	23	2.42%	17	1.79%	8	0.84%	1	0.11%
	19:30 – Operation closing time	25	2.63%	25	2.63%	32	3.37%	17	1.79%	23	2.42%
Hazard pattern	Falls	286	30.11%	197	20.74%	151	15.89%	110	11.58%	49	5.16%
	Entrapment	1	0.11%	1	0.11%	0	0.00%	0	0.00%	1	0.00%
	Injuries caused by falling objects	0	0.00%	1	0.11%	32	3.37%	0	0.00%	0	0.00%
Injured body region	Multiple body regions	79	8.32%	69	7.26%	37	3.89%	29	3.05%	9	0.95%
	Head and neck	73	7.68%	47	4.95%	18	1.89%	26	2.74%	23	2.42%
	Lower extremities	46	4.84%	33	3.47%	53	5.58%	24	2.53%	5	0.53%
	Upper extremities	46	4.84%	29	3.05%	34	3.58%	13	1.37%	5	0.53%
	Trunk	22	2.32%	25	2.63%	21	2.21%	11	1.16%	0	0.00%

In each cell, the two numbers give number of cases and the percentage in all injuries, respectively. Cases with unknown hazard pattern, injured body region and other major cause were not listed. Major causes with the percentage less than 5% of all injuries were not listed.

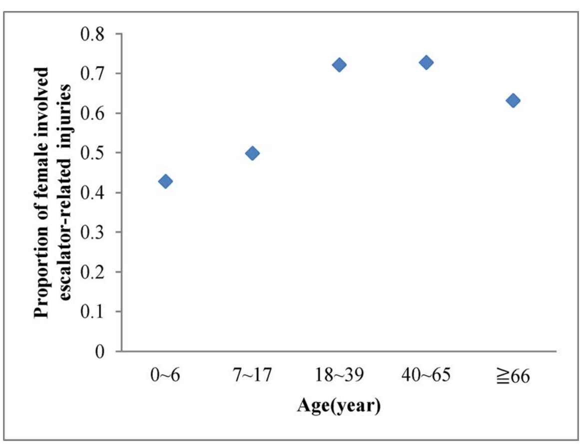

Fig. 4. Distribution of female involved escalator-related injuries by age group.

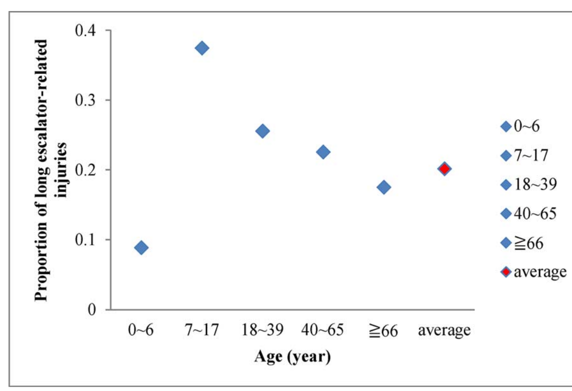

Fig. 5. Distribution of long escalator-related injuries by age group.

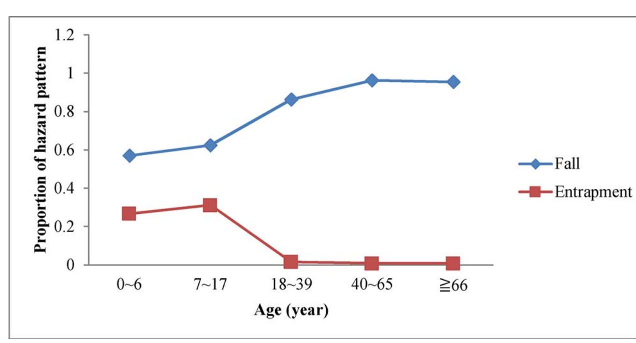

Fig. 6. Distribution of hazard pattern according to age group.

with age for slips, trips and falls on level surfaces. A possible reason, they explained, is that persons are progressively more likely to suffer slipping, tripping, and falling accidents as they get older, or conversely an older person is more likely to suffer an injury which causes the accident to be noticeable. Chi and Wu (1997) also suggested that rates of falling, slipping and tripping accidents had a significant rising trend with age. These accidents of the aging population could have been caused by their slowness in escaping from injuries, a general lack of physical strength and less flexibility to adjust posture to regain balance. The current approach adopted by the Guangzhou Metro is to encourage the elderly and handicapped passengers and those carrying handcarts or baby carriages to take the elevators instead.

Unlike other major accident causes, male passengers (35 out of 50, Table 7) tend to have accidents caused by unhealthy physical condition and unhealthy passengers were more likely to be involved in injuries without company (32 out of 50). This is probably due to the effect of drunkenness. As mentioned above, out of the unhealthy passengers, 24 passengers were under the influence of alcohol, while alcohol may cause drowsiness, or affect the balance and safe mobility of an adult.

Long escalator may be a potential source of risk. On a long escalator, passengers tend to have accidents caused by other passenger's movement (52 out of 168, Table 7). One possible reason is that passengers are more likely to walk on a long escalator in order to save time. For example, a long escalator in Xichang station is 45 m long and 20.6 m high and riding this escalator takes more than one minute, which may result in more injuries due to its steep gradient. In addition, some passengers can't wait a relative long time for riding the escalator, especially on rush hours.

As falls accounted for more than 90% of all injuries, major causes with the percentage more than 5% of all injuries were more likely to cause falls, such as failing to stand firm (30.11%), carrying out other tasks (20.74%), other passenger's movement (15.89%) and so on. Besides falls, other passenger's movement was also likely to result in injuries caused by falling objects. The main reason is that several passengers may not take care of their luggage when riding the escalator, thus luggage may fall out and injure other passengers.

The association between injury location and major cause showed some interesting results. As can be seen from Fig. 7, loss of balance, carrying out other tasks and not holding the handrail caused the largest number of injuries to multiple body regions, followed by head and neck. Both upper and lower extremities was more likely to be caused by other passenger's movement, while the head and neck regions tend to have accidents caused by unhealthy physical condition.

Significant associations between major accident causes and other contributing factors could also help to reconstruct the accident scenarios and develop prevention measures. Failing to stand firm and not holding the handrails were more likely to cause accidents on escalators traveling upwards. The multiple body regions and working hours (9:30–17:29) were the most frequently identified in their categories for major accidents causes, with the exception of unhealthy passengers. A peak incidence at night (19:30 − operation closing time) has also been reported for unhealthy passengers.

The correlation between the need for an ambulance and the injured body region is also one of the stronger associations. As shown in Fig. 8, head and neck injuries accounted for the highest proportion of all injuries that need an ambulance (33.03%), followed by multiple body regions (24.42%) and lower extremities (15.84%). This is because head and neck are the most important part of human body, head and neck injuries may lead to very serious consequences. Therefore, head and neck injuries were more urgent to need an ambulance than other body injuries.

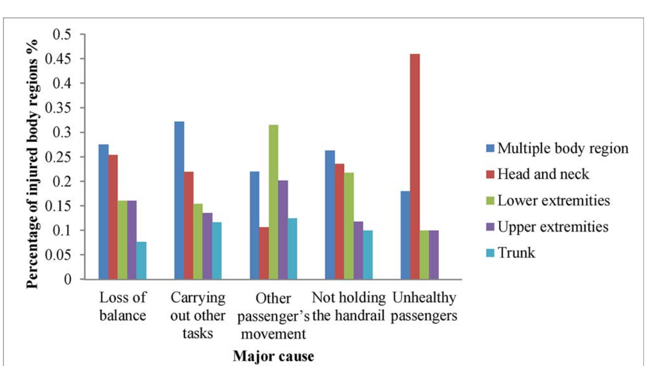

Fig. 7. Distribution of injured body regions according to major cause.

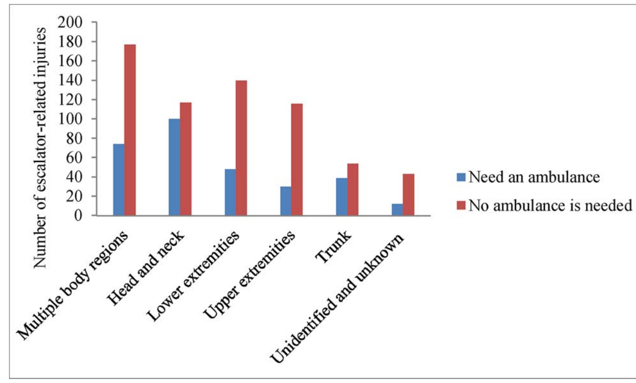

Fig. 8. Distribution of injured body regions according to need for an ambulance.

4.2. Strategies for injury prevention

This study describes escalator-related injuries in Guangzhou metro stations and analyzes the frequency distribution of different contributing factors and their significant association with each other. The results could provide guidance for discovering effective countermeasures for different groups of passengers at high risk of escalator riding accidents. For example, for elderly passengers aged 66 years and above, whose injuries were caused by failing to stand firm, the current approach is to encourage them to take the elevator instead. In Guangzhou Metro, a few stations provide stairlift that deliver wheelchair users between the platform and concourse, while most of the rest of stations have an accessible elevators connecting the platform and concourse. However, this preventive approach may not be a practical one if the elevator provided in the metro station is not easy to access, especially on rush hours.

For children aged 6 years and younger, baby carriages were involved in a significant proportion of escalator-related injury events and most injuries occurred to children as a result of falling out of the baby carriage. These accidents might have been prevented by enhancing the publicity of escalator safety rules. The following safety rule was made to protect baby "Handcarts and baby carriages are prohibited on the escalator", however, it may be difficult to notice on the interior panel (Fig. 3). TRTC (Taipei Rapid Transit Corporation) can provide good experience for Guangzhou Metro. It reminds passengers of the safety guide for an escalator ride with pamphlets and broadcasts and statistics have shown that escalator riding accidents have been reduced after these prevention measures were implemented. Besides, appropriate signing indicating the location of elevator should be provided to prevent accidents to young children (aged below 7 years) caused by falling out of the baby carriage.

Falls for any reason are of importance to passengers, especially to older adults. Unintentional injuries, specifically falls, are the leading cause of injury-related mortality and morbidity among older adults (CDC, 2006). Falls are mainly caused by individual factors, such as failing to stand firm, carrying out other tasks and not holding the handrail. How to improve the safety awareness of passengers is a common issue. The current approaches adopted by Guangzhou Metro are not enough. Besides the pamphlets mentioned above, new media may be a more useful propaganda tool for young and middle-aged passengers, such as app and microblog. Furthermore, the escalator safety rules are easier to accept by using funny and real pictures rather than boring words, thus brochure or leaflet with funny pictures about escalator safety rules may be useful for children and elder passengers.

Children who are younger than 7 years may be at higher risk for escalator-related entrapment injuries. Holding a young child's hand or carrying the child while on an escalator may be an effective measure to prevent him or her from putting hands or fingers between the escalator step and the sidewall or getting close enough to the sides to allow entrapment of loose clothing, shoelaces, or drawstrings. Escalator designs that reduce the gap between the steps and the sidewall or shield against access to the gap could decrease entrapment risk by removing the potential hazard from the environment (Mcgeehan et al., 2006).

On the basis of the findings in this study, the proportion of the long escalator involved injuries (20.2%) in all escalator-related injuries were much higher than its proportion of all escalators (5.8%), indicating that the long escalator may be a potential risk factor. If a long escalator is unavoidable in metro stations, adopting a larger transition radius (the distance it takes to move from a 30∘ incline to a 0∘ incline on the escalator) can reduce the most common type of escalator accidents—a fall due to failing to stand firm (Welch, 2002). In particular, for escalators with over 10 m in rise, a larger track radius provides better riding comfort while driving from the incline section into landing. APTA Escalator guidelines suggest that the upper radius be at least 2.6 m for heavy duty escalators of less than 10 m rise (Welch, 2002). According to “Safety rules for the construction and installation of escalators and passenger conveyors” in China, the Guangzhou Metro requested of their contractors who provided escalators with over 10 m in rise, that the track radius not be less than 3 m.

Although accident data collected by Guangzhou Metro contain a lot of information, there is still a lack of useful information. The authors suggest that for future escalator-related accidents records, the accident report has to cover the major parameters of the escalator (length, gradient and rated speed), the activity of the victim just before the accident, the location of the accident at the escalator, any involved product (slippers, shopping bags, and footwear), any medical treatment, what went wrong, opinion of the respondent on the causes of the injury and personal characteristics of the passengers (Hertog et al., 2000; Chi et al., 2006).

5. Conclusions

The current study provides statistical evidence to identify accident patterns and high risk groups through analysis of 950 escalator-related injuries during 2013–2015.

Female victims were involved in greater proportion (65.9%) of escalator-related injuries and elderly women (31.58%) were more likely to be involved in escalator-related injuries. The main reason is that women’s a physical strength, flexibility and sensitivity are weaker than men’s. Compared with female passengers, male passengers tend to have accidents caused by unhealthy physical condition.

Elderly passengers (aged 66 years and above, 49.3) account for the highest proportion of all escalator-related injuries, followed by middle-aged (aged 40–65 years, 22.6%) and young (aged 18–39 years, 20.1%) adults, and the least proportion lies on teenagers (aged 7–17 years, 1.7%). Moreover, age was associated with all factors except for need for an ambulance and the distribution law of these factors differed with age groups. There was a consistent increase with age in the proportion of injuries that were caused by a fall, conversely, there was a consistent decrease in the proportion of injuries that were attributed to entrapment by age group. Unlike other age groups, passengers aged 18–39 years were more likely to be involved in escalator-related injuries when they are without company. For elder passengers (aged 66 and above), failing to stand firm (19.26%) was the main causes of escalator-related injuries, while carrying out other tasks (6.84%) accounted for the highest proportion of escalator-related injuries for middle-aged passengers (aged 40–65 years).

Major cause was associated with all factors except for need for an ambulance. Of all major causes in this study, major causes with the percentage more than 5% were further discussed and analyzed. Unlike other major accident causes, unhealthy passengers were more likely to be involved in injuries without company (32 of 50). The multiple body regions and working hours (9:30–17:29) were the most frequently in their categories for listed major accidents causes, with the exception of unhealthy passengers. Lower extremities was more likely to be caused by other passenger’s movement, while the head and neck regions tend to have accidents caused by unhealthy physical condition.

The results can provide prevention strategies for different groups of passengers at high risk of escalator-related injuries.

For passengers, female passengers should be more careful than male passengers and try not to wear high-heeled shoes when riding an escalator. Older adults should be informed of possible dangers associated with an escalator and should use caution while riding an escalator and especially when stepping on or off. Also, older adults should not try to walk up a moving escalator, or carry large objects, while riding an escalator since these behaviors appear to be associated with an increased risk of falling. Young children should be supervised closely and should not be transported in a baby carriage when riding an escalator. All passengers should use caution and remain alert while riding a long escalator.

For metro operation corporation, appropriate signing indicating the location of elevator should be provided to prevent accidents to elderly passengers (aged 66 years and above). Secondly, the operation department should step up publicity efforts to enhance safety awareness of passengers through different media. Thirdly, following a stricter design code can be most effective for preventing entrapment injuries of all age groups. And last, the preventive measures of regular patrol and periodic device test should be strengthened to ensure safety of escalators, especially long escalators.

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