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The safety margin and perceived safety of pedestrians at unmarked roadway

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ABSTRACT

Many pedestrians cross out of crosswalks (i.e., unmarked roadway) in developing countries, but researches about their safety are under reported. This study explored safety related factors and their casual relations at unmarked roadway. Videos of 254 pedestrians' crossing process were analyzed objectively on safety and evaluated subjectively on perceived safety. The two safety indexes are consistent on important factors, with higher running frequency reduce safety while bigger group size increase safety. The two factors had contrary effect on pedestrian speed, which is positively related with safety. Higher looking frequency before crossing also enhance safety, partly by reducing running frequency and increasing going backwards with its planning nature. Longer waiting time before crossing can facilitate this planning behavior while at the same time leads to bigger group size. Buses are safer than cars, but they are not perceived as safer. In situations where only some vehicles yield, yielding ones bring danger due to sight blocking of unyielding ones in adjacent lanes. These findings can be applied to the design of intelligent transportation systems and the education of drivers and pedestrians to improve safety.

1. Introduction

1.1. Pedestrian safety at unmarked roadway

Pedestrians are vulnerable road users in the world. Every year, pedestrians and other vulnerable road users like cyclists accounted for 46% of global road traffic deaths (WHO, 2009). In developing countries, the problem is more serious. In China, 40% of the trips are completed by walking (Yang, Deng, Wang, Li, & Wang, 2006), exposing many pedestrians to danger. In 2007, 21,106 pedestrian deaths and 70,838 injuries happened, making respectively 25.85% and 18.62% of the total deaths and injuries on the road (Automobiles, 2009). Except for some natural disasters, these accidents are all caused by human factors. According to CRTASR (2005), pedestrians' "*illegally crossing through roadway*" leads to 113, 83 accidents, and as the more vulnerable part, pedestrian suffered much in these accidents. In China, if there is no overpass or underpass, pedestrians should only cross at crosswalks unless there are no such facilities. Therefore, "*illegally crossing through roadway*" means that pedestrians cross at unmarked roadway (i.e. arbitrary road section without crosswalks rather than unmarked crosswalks, which exist at intersections). Unmarked roadway crossing is not only a severe cause of accidents in China. In many developing countries, traffic regulations were not well obeyed, resulting in many problems at roadway. Al-Ghamdi (2002) found that

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in Saudi Arabia 77.1% of pedestrians were struck either out of crosswalk area or in where no crosswalk existed. These facts call for attention of pedestrians crossing at unmarked roadway.

Despite the severity in accidents, there were very few studies focusing on unmarked roadway. Researches in virtual contexts investigated how pedestrian make decisions before crossing (Cavallo, Lobjois, Dommes, & Vienne, 2009; Lobjois & Cavallo, 2009), but they did not care about the effect of crosswalks. Observational and experimental studies in real contexts were mainly about pedestrian behaviors at signalized crosswalks (Hatfield & Murphy, 2007; Rosenbloom, 2009; Tiwari, Bangdiwala, Saraswat, & Gaurav, 2007) and marked or unmarked crosswalks (Ragland & Mitman, 2007; Rosenbloom, Ben-Eliyahu, & Nemrodov, 2007). Unmarked roadway crossing was rarely reported in current studies and the mentioned ones usually did not primarily focus on unmarked roadway itself. For example, Airault and Espié (2005) modeled whether pedestrian would cross at or out of crosswalks as an example to show pedestrians' choice of facilities. Chu and Baltes (2001) found pedestrians evaluated crossing through roadway to be more difficult than at crosswalks. In their study, roadway crossing was only one of the many evaluated variables. Similarly, Oxley, Fildes, Ihsen, Charlton, and Day (1997) conducted a more related study at unmarked roadway focusing on age differences in crossing behavior.

To address this problem received relatively little attention, this study aims to explore how the demographical, contextual and behavioral factors related to each other, how they affect safety and their relative importance. The following part is about safety indexes and current safety factors frequently mentioned in literature (at other crossing facilities).

1.2. Safety measurement

This study focuses on pedestrian safety and its related factors. This aim determined the importance of a well-fitted measurement of safety. Crash rate is an accurate measurement and it has been used in several studies about pedestrian safety (Harruff, Avery, & Alter-Pandya, 1998; Leden, 2002; Lefler & Gabler, 2004). This index, however, needed several years of data collection. Moreover, crash data is post hoc data, thus has no detailed information about situational and behavioral aspects (Svensson & Hydén, 2006). Instead, this study adopted two measurements that could be collected relatively quickly and in detail. That is, an objective measurement with behavioral data and a subjective measurement with safety ratings.

1.2.1. Safety margin

Safety margin is an objective measurement of safety, which means the difference between the time a pedestrian crossed the traffic and the time the next vehicle arrived at the crossing point (Chu & Baltes, 2001). Suppose that a pedestrian's path will intersect with the path of the nearest approaching vehicle of the same lane at point "A". Before the interaction, the pedestrian reaches "A" at time T_1, and afterwards the vehicle arrives at "A" at time T_2, then the safety margin is $T_2–T_1$. This meant that if the pedestrian had been $T_2–T_1$ slower or the vehicle had been $T_2–T_1$ faster, a collision would happen. There are slight differences in the definition of safety margin in different studies (Chu & Baltes, 2001; Lobjois & Cavallo, 2009; Tung, Liu, & Ou, 2008). Fundamentally, however, it is the time left when subtracting the time needed from time available to cross the road before a vehicle. It has been used as dependent variable in several pedestrian safety researches (Cavallo et al., 2009; Lobjois & Cavallo, 2007, 2009; Oxley, Lenné, & Corben, 2006; Tung et al., 2008). They conducted experiments in virtual environment, thus having both negative safety margin to indicate dangerous crossings and positive ones to indicate safe trials. In real crossings, however, it is not likely to observe a negative safety margin (an accident), thus safety margin is considered as an indicator of *relative safety*, with larger safety margin representing more safety. Since studies in virtual environment usually conduct experiments on one lane road, there is only one safety margin during a crossing. This study was conducted at a six-lane road hence each pedestrian had six safety margins. To assure pedestrian safety, safety margin here is defined as the smallest one of the six values.

1.2.2. Perceived safety

Perceived safety was a subjective measurement of safety. It signified perceived degree of risks. As stated above, safety margin can only reflect pedestrian safety relative to only one vehicle, but in complex situations where pedestrian safety is actually influenced by several vehicles simultaneously, a holistic index like perceived safety will be a preference. Moreover, pedestrians behave based on their perceived safety. Herms (1972) found that pedestrian had a false sense of safety that made them not as careful when crossing painted crosswalks as crossing unpainted ones, which lead to higher accident rate. This means that *perceived safety* is important for understanding of pedestrian behaviors and improving safety. Therefore, subjective safety is adopted to describe pedestrian safety from another angle. Carter, Hunter, Zegeer, Stewart, and Huang (2006) asked experts to rate safety of pedestrian and bicycle facilities at intersections. They gave evaluators video clips for each site (this is clues given to raters). The evaluators viewed these data as if they were pedestrians at the crosswalks and then rated their sense of safety on a six-point scale. This was an evaluation of *environment* with six levels. In a distraction study by Nasar, Hecht, and Wener (2008), trained observers evaluated on the spot whether certain action would put the pedestrian at risk of getting hurt. This was an evaluation of pedestrian behavior in specific context with only two levels ("unsafe" and "okay"). Integrating the two kinds of evaluations, this study asked evaluators to rate pedestrians crossing safety according to the context and behaviors in the video on a seven-level scale.

1.3. Factors related to safety

Safety related factors are hot topics in previous pedestrian studies, mostly at crosswalks. The addressed factors mainly fell into three categories: demographical, contextual and behavioral.

1.3.1. Demographic aspect

This aspect deals with pedestrians' demographic information like gender and age. In crash data analysis, males had higher death rates. NHTSA (2007) showed that more than two-thirds (70%) of the pedestrians killed in 2007 were males. Harruff et al. (1998) found that males had a 50% higher fatal rate than females. In intentional study, females were found to have higher perceived risk (Holland & Hill, 2007). In behavioral studies, females behaved more conservatively: cross on red less (Rosenbloom, 2009) and wait more before crossing (Hamed, 2001). In fact, Tiwari et al. (2007) found that females waited 27% longer than males. In simulated context, Holland and Hill (2010) found much more unsafe crossings for males than females. Therefore, it is likely that females are safer than males in road crossing.

Age also plays an important role in pedestrian safety. Young pedestrian under 15 and elderly pedestrians over 70 had always been the over represented age groups in pedestrians involved accidents (NHTSA, 2007). For old pedestrians (60–80), they usually adopt lager time gaps (Cavallo et al., 2009; Lobjois & Cavallo, 2009). They had similar behavioral patterns with young pedestrians (20–30) with no time constraint. Under time constraint, however, they accepted smaller and smaller time gaps, which did not exist in young groups (Lobjois & Cavallo, 2007). For children and teenager pedestrians, researches usually care about their attention development, which is not the focus here.

1.3.2. Context related aspect

Vehicle flow and speed are important factors to pedestrians' safety. Pedestrian crash rate increased with higher traffic flow and speed (Gårder, 2004). Speed also indirectly cause dangers, as pedestrians under high speed had little time to react. They also tended to overestimate their distance with vehicles (Tung et al., 2008). For vehicle type, Lefler and Gabler (2004) found that light trucks and vans were more dangerous than cars to pedestrians. Hamed (2001) found pedestrians were more likely to end waiting and begin to cross if the oncoming vehicle was a large bus, suggesting higher safety of buses. Group size is the number of pedestrians crossing together. Pedestrians in groups are usually slower (Gates, Noyce, Bill, & Ee, 2006) but it is easier to gain the right of way against drivers than individuals (Himanen & Kulmala, 1988).

1.3.3. Behavioral aspect

Before crossing, waiting time is factor to be considered. On the one hand, waiting too long made pedestrian bold, hoping to force vehicles to reduce speed for them (Hamed, 2001), and thus put them in risk. On the other hand, studies have shown that pedestrians would look at left and right to check the vehicles or look at lights during waiting (Geruschat, Hassan, & Turano, 2003). These head movements help to focus on source of potential danger and improve safety.

During crossing, distractors can reduce caution (Bungum, Day, & Henry, 2005) and among them, phone related distractors were studied by several methods including field observation (Hatfield & Murphy, 2007), "pretend road" method (Nasar et al., 2008) and virtual road experiments (Neider, McCarley, Crowell, Kaczmarski, & Kramer, 2009). They all proved a negative relation of cell phone use with cautious behaviors. Running during crossing was used as an index of risky behavior (Rosenbloom et al., 2007; Yagil, 2000). Although running usually leads to faster crossing, higher speed was considered safer for reducing exposure time to potential dangers (Geruschat et al., 2003; Murray, 2006).

1.3.4. Potential factors

Except the crash data analysis and experiments in the virtual environment where the facility information is not that clear, most of the above factors are studied at crosswalks. Considering the less protection and control at unmarked roadway, these factors' effect may change, thus need to be checked in the new situation. Besides them, we proposed other variables that may be important to pedestrian safety. Namely, in the contextual aspect, whether vehicles yield to pedestrians during interactions; in the behavioral aspect, distractors before crossing, time spent on the median (middle of two-way road), frequency of going backwards, number of stops and duration of the stops. For a summary, see Table 1.

1.3.5. Overview of the paper

This paper has main interest in the following issues: relations of the factors reviewed above; how did they influence safety and perceived safety and their relative influencing power and importance. Correspondingly, the method part gathered field data about factors and safety measures. Then the results part first conducted a correlation analysis, followed by a stepwise regression to determine the variables closely related to safety. Both the correlation and regression can pick out the important safety related factors that can be included in a model with assumed relations based on literature. So finally, path analysis was used to fit the model and get the direct/indirect causal mechanisms on safety margin. Path analysis is an extension of but not the same as multiple regression. First, it is a statistical modeling approach but not just data-driven. All paths have to make sense based on daily experience or literature. Second, it does not parallel all independent variables as in regression. This is more realistic in the current crossing situation since there are clear causal relationships because of chronological order. Finally, path analysis is good at analyzing complex relationships with detailed decomposition of correlation

Table 1
Variables considered in the observation study.

Aspects	Variables	Descriptions and coding methods
Demographic	age	Teenage: <20, young adult:[20,30), middle-aged: [30,50], age_{50+} > 50
	gender	Male, female
Contextual	groupSize	Number of pedestrians crossing together of both directions
	vehi_yield	Whether vehicle change speed or direction for the pedestrian
	vehi_flow	Vehicles passed per minute; calculate for each pedestrian falls in that minute
	vehi_type	Type of the vehicle that yielded safety margin; bus, car
	vehi_spd	Speed of the vehicle yielding safety margin
Behavioral	wait	Time spent at curb before cross after arrival at the site
before	before_look_freq	Frequency of looking at vehicles before crossing; count head movements
crossing	before_look_dur	Duration of looking at vehicles before crossing
	before_distractor	Distractors before crossing; carry stuff, eat/drink/smoke, phone, groom, talk
during	cross_distractor	Distractors during crossing; carry stuff, eat/drink/smoke, phone, groom, talk
crossing	run_freq	How many times pedestrian run
	path_style	Style of pedestrian path (crooked or straight forward)
	backward	Frequency of going backwards to yield to vehicles
	stops	Number of stops during crossing; a stop means hesitate for >0.04 s
	stopWait_time	Time duration of standstill in all stops
	near_side_time	Time spent at near side of the road
	far_side_time	Time spent at far side of the road
	median_time	Time spent on the median line (middle of two-way road)
	cross_look_freq	Frequency of watching for vehicles; count head movements
	cross_look_dur	Time of looking left and right/ crossing time
	cross_spd	Pedestrian crossing speed; distance/cross time

Note: Time is coded in seconds, and speed in m/s. Detailed coding of distractors and groupSize is presented in Section 2.2.

coefficients that can tell direct effects from indirect effects (Qiu et al., 2007), which can deepen understanding of the related factors.

2. Methods

2.1. Observation location

A typical site was chosen near the North Bus Station of Hang Zhou, China. It is a busy site with 2826 vehicles and 757 pedestrians per hour. This two-way road has three lanes on each side and a total width of 20.3 m. The "imagined" crosswalk is obliquely intersected with road, and even the farther gap is only 82 m from the nearest signalized crosswalks. Sketch of the site is shown in Fig. 1. Most unmarked roadway crossing sites in China shares the characteristic that at one side there are attractive sites like shopping center, grocery while at the other side many people gather because of bus stations or residents blocks. Compared with detouring to crosswalks nearby, people prefer to cross directly. This common characteristic means that the site chosen is representative of unmarked roadway in other urban areas of China.

2.2. Observation and coding

Two synchronized cameras were set on two sides of the crossing site to take videos there on two temperate days, namely from 10 AM until noon on October 14th and from noon until 4 PM on November 17th. One camera was set on a high building

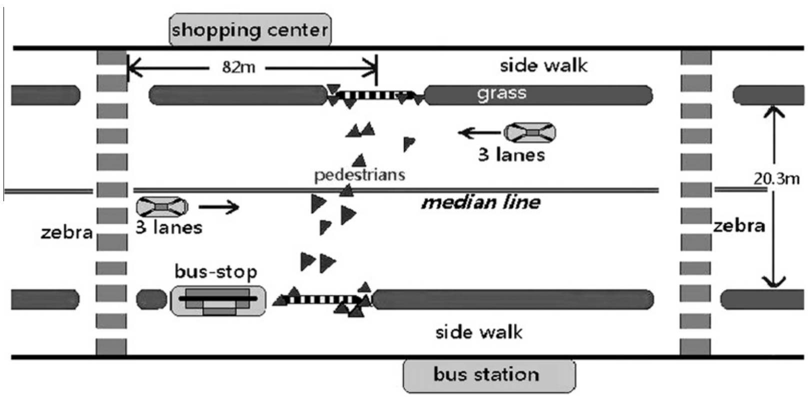

Fig. 1. Sketch of the site.

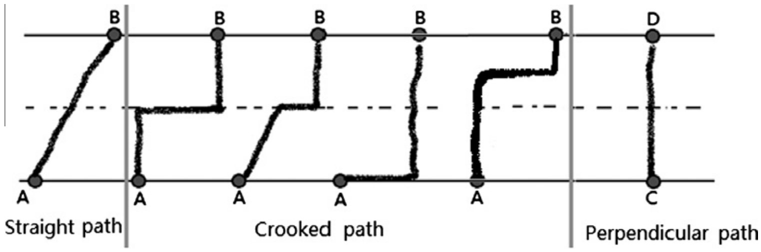

Fig. 2. Illustration of path style coding.

to get a bird's eye view while the other beside the road to capture pedestrians' detailed behaviors. The video was played in Adobe Premiere Pro CS4 version 4.0.1 with time display accuracy of 0.04 s. The coding process has two steps.

2.2.1. Select pedestrians

This step aims to make sure pedestrians chosen can be observed clearly during the crossing without being blocked by vehicles. We neglected pedestrians in the following category: Crossing on foot with a bicycle or motor, no vehicles present during crossing, stay in a very large group exceeding 12, cross in the gaps between lines of stopped vehicles, and cannot be seen clearly at any moment after arrived.

2.2.2. Coding of the variables

Most variables could be coded with the description in Table 1, but further remarks are needed for some variables (e.g. age, groupSize). The "age" was estimated and planned to be coded by decades. It turned out that only a few pedestrians older than 50 were observed, so the age group older than 50 years old was reorganized as "age_{50+}".

To simplify the coding results, pedestrians with multiple distractors were only coded with the most influencing distractor in terms of safety (assessed by our researchers). The order of influence is "phone related distractor", "talk", "eat/drink/smoke", "carry stuff", and "groom". However, this had little influence to the results as only very few pedestrians have multiple distractors. For "carry", pedestrians have to be seen carrying some stuff having influence on their behavior, e.g. luggage. For "eat", pedestrians must have food in their hands *and* eat them. "Groom" means pedestrians combed their hairs with fingers or sprucing.

GroupSize is the number of people crossing together (familiars or strangers). In the first 1/2 of the road, if pedestrian X has crossed more than half of the 1/2 road width before Y begin crossing (same or contrary direction) they are not in a group; otherwise, they belong to one group. Then the far side groupSize was counted in the same way. Final groupSize is average of the two.

For all the behaviors that are related with looking at vehicles, a noticeable turn of the head is needed (similar to Bungum et al., 2005). Vehicle speed is measured based on the distance between road markers and the time a vehicle used to cover that distance.

For path style coding, see the illustration in Fig. 2. The start points were their initial positions and the ends were their destinations. If a pedestrian's path was roughly the shortest of all possible paths (go straight ahead to destination), then it is "straight" path style. If a pedestrian adopted a curve path then it is "crooked" path style, it could be a combination of the four examples shown. That is, pedestrians could change their directions at any of the lanes, regardless of whether it was the median line or not. If a pedestrian's path is perpendicular to the road, we coded it as "perpendicular".

Two young (age 21 and 22) male evaluators[1] frequently crossing at unmarked roadway evaluated all pedestrians' safety according to the videotape. Before that, they were taken to the site and crossed there three times alone on a Wednesday afternoon. Then the evaluators were asked to watch videos of their own and that of other pedestrians on a big screen. The instruction was, "Watch carefully and compare with your own video, then imagine you are that pedestrian, and rate how safe you are to cross in that way in that situation". The safety score was given on a seven-point scale with higher safety score representing more safety.

3. Results

This part started with a descriptive analysis to get the general information of observed sample, followed by correlation analysis to figure out correlations between the factors and safety indexes. Then stepwise regression got the variables that closely related to safety. Finally, an assumed model of complex causal relations was constructed based on preceding results and checked by path analysis.

[1] Three young (aver. Age 24.0 years old) and three old (aver. Age 63.3 years old) evaluators were invited to evaluate 60 pedestrians. No significant difference of the evaluation results was found between these two groups of evaluators ($r = 0.597$, $p < 0.000$; $t(59) = 0$, $p = 1$). This means that it is reasonable to choose young evaluators instead of old ones who may have difficulty watching video for a very long time.

Table 2
Descriptive statistics.

Variable	Level	*N*	Variable	Level	*N*	Variable	Mean	S.D.
gender	Female	118	run_freq	0	173	wait	2.8	5.47
	Male	136		1	66	before_look_freq	1.1	1.94
age	Teenage	14		2	15	before_look_dur	2.3	4.72
	Young	104	backward	0	225	median_time	2.6	6.32
	Middle_age	112		1	25	near_side_time	14	6.84
	Age_{50+}	24		2	4	far_side_time	11.6	3.97
before_distractor	No	148	stops	0	151	stopWait_time	2.1	4.32
	Carry	38		1	74	groupSize	2.8	1.57
	Eat/drink/smoke	15		2	23	cross_look_freq	5.4	2.42
	Phone	13		3	5	cross_look_dur	0.6	0.21
	Groom	12		4	1	vehi_flow	43.9	10.88
	Talk	17	path_style	perpendicular	71	vehi_spd	7.3	2.47
cross_distractor	No	129		straight	30	cross_spd	1	0.35
	Carry	37		crooked	153	safetyScore	−0.01	0.89
	Eat/drink/smoke	17	vehi_yield	no	130	safetyMargin	2.5	0.83
	Phone	12		yes	124			
	Groom	31	vehi_type	car	168			
	Talk	9		bus	86			

3.1. Descriptives and correlation analysis

Table 2 is the descriptives of 254 pedestrians. It shows that gender is roughly equally distributed, but the age groups differed a lot. Young and middle-aged pedestrians account for 85% of the whole sample. Pedestrians looked at vehicles once (1.1) before crossing and did that for five times (5.4) during crossing. When crossing, pedestrians have interactive behaviors with vehicles like running (31.9%), stopping (40.6%) and going backwards (11.4%). Generally, pedestrians have safety margin of 2.5 s, meaning that pedestrians will be knocked down if they had been 2.5 s slower. SafetyScore is the normalized score from the safety evaluation. It almost equals to zero (−0.01), showing that most pedestrians were not considered behaving in extreme safe or dangerous ways. Vehicles at the site drive at a relatively low speed (7.3 m/s) when approaching the crossing site and nearly half (48.8%) obviously changed speed for the pedestrians.

Pedestrian demographic, behavioral and contextual factors are related with each other. The following correlation analysis (see Table 3) provides an overview of these relations that will facilitate understanding of other analysis results.

Waiting time positively related with group size ($r = .12$, $p < .05$) and looking frequency before crossing ($r = .76$, $p < .001$). That is, longer waiting time implies bigger pedestrian group and more frequent look at vehicles before crossing. The latter one itself also indicates less running ($r = -.16$, $p < .01$) and more going backwards behaviors ($r = .13$, $p < .05$). Going backward often happened when pedestrians stopped during the crossing ($r = .29$, $p < .001$) and when the vehicle flow is high ($r = .18$, $p < .01$).

Pedestrian speed is higher when they have higher running frequency ($r = .25$, $p < .001$), and lower when they stopped more ($r = -.20$, $p < .01$) or involved in bigger groups ($r = -.15$, $p < .05$). Vehicle speed, however, is higher for smaller group size ($r = -.19$, $p < .01$), lower vehicle flow ($r = -.13$, $p < .05$) or it is a bus ($r = -.35$, $p < .001$). Vehicles yield more to pedestrians who stopped more ($r = .23$, $p < .001$) and looked more frequently at them ($r = .20$, $p < .01$), but less likely to yield to young pedestrians ($r = -.16$, $p < .05$).

The correlation between safety margin and safety score is $r = .23$, $p < .001$, showing some accordance. The factors related with them were analyzed in detail in next section.

3.2. Safety margin predictors

Stepwise regression was conducted for all the factors with safetyMargin as dependent variable. The analysis aims to find important factors among all the listed potential predictors after considering partial correlations. We set the entry probability of F at 0.05 and removal at 0.1. Table 4 presents the regression results.

The variables in the table are variables emerging as significant predictors. They have significant linear relationship with safety margin ($F(8,245) = 9.18$, $p < .001$) and can explain 23.1% of the total variance (adjusted $R^2 = .21$). Among these variables, vehicle type is the most important predictor. Pedestrians have lower safety margin when the oncoming vehicle is a car than a large bus. Pedestrian age also matters, with middle-aged pedestrians being safer than other age groups. It is worth noting that the more frequent pedestrian ran the lower safety margin they had (Coefficient = −.175, $p = .003$). However, for pedestrian involved in bigger groups, safety margin become bigger. This is also true for those crossed the road with higher speed and went backwards more frequently. The higher frequency pedestrians looked left and right before the crossing, the safer they were. It is interesting that pedestrians who ever settled their hair or clothes during crossing had bigger safety margin than those who did not.

3.3. Perceived safety predictors

The reliability of the safety evaluation is acceptable: Pearson correlation of standardized score from two evaluators showed significant accordance ($r = 0.58$, $p < .001$).

Similar to the stepwise regression method used in safetyMargin, another regression analysis with safetyScore was carried out and Table 5 shows the results. The linear regression model is significant ($F(6,247) = 18.54$, $p < .001$) with a R^2 of 0.31 (adjusted $R^2 = .29$).

Again, run frequency hampered perceived safety as it did on safety margin. More frequent running led to lower perceived safety. Group size effect on perceived safety also remained as that on safety margin, with bigger group of pedestrians being considered safer. Although two genders were similar in safety margin, males are considered under more risk than females. It is surprising that vehicles yielding to pedestrians were evaluated more dangerous than unyielding ones. However, distractors like using phone and eating, drinking or smoking during crossing showed their effect as expected. Pedestrians coupled with these distractors were considered less safe than undistracted ones.

3.4. Path analysis results

The assumed model is built in the following steps (see Yano, Sato, Björkman, & Rylander, 2002): First, select the variables significantly correlated with safety margin (seven factors, before_look_dur showed much accordance with before_look_freq in all the relations, but it did not prove significant in regression, so it is excluded and only before_look_freq was kept for simplicity. On the contrary, cross_spd is significant in the regression and significantly related with three other important factors, so it is included). Then, choose other variables that may cause the seven factors and built the model based on experience and literature. The distractor related variables are not included because too dummy variables make the model crowded, given the limited information they carry due to small number of distracted pedestrians. The model is presented as Fig. 3(with no coefficients).[2]

The path analysis was conducted by Lisrel 8.7.0 using the Maximum likelihood estimation method. The standardized estimates were presented as Fig. 3.

The bold lines represent relations between factors and others show how the factors related with safety margin. For model fitness, $\chi^2(29) = 23.81$, $p = .74 > .05$, root mean square error of approximation (RMSEA) = 0.00 and p-value for test of close fit (RMSEA < .05) = .99 > .5, goodness of fit index (GFI) equals 0.98 and adjusted goodness of fit (AGFI) is 0.97. All these indexes show a good model fit. Since all the paths are significant and the whole model fitness is good, the model remains as assumed. It should be noted that after considering all the mediated paths, waiting time, looking frequency before crossing gained more power while other variables' power were impaired (e.g. run_freq), compared with the regression analysis. The following Fig. 4 shows the "new" effect of the factors on safety margin.

In Fig. 4, the darker bars present indirect effect of factors on safety margin while the lighter ones present the direct effects. They have positive values for improving safety and negative values for impairing safety. Factors are sorted based on decreasing size of their effect (absolute value) from down to top in Fig. 4. Vehicle type still has its first place as in regression, but looking frequency come to second because of its effect on run_freq and going backward. Waiting time did not even show up in regression results, but it jumps to the fourth place by following two routes: (1) "Wait → GroupSize → ⋯ → SafetyMargin", which presents the power of large crowds because longer waiting time leads to larger crossing groups that could have higher priority and suffer fewer risks; (2) "Wait → before_look_freq → ⋯ → SafetyMargin", which indicates that longer waiting time also improved safety by increasing the frequency of looking at vehicles before crossing. Contrary to the variables with increased power, unsafe effect of running frequency is decreased by the mediator "cross_spd". Higher running frequency led to higher speed that can decrease exposure of pedestrians, thus improve safety. Positive effect of groupSize was also diminished a little by slower crossing speed for pedestrian in bigger groups (standardized indirect effect −0.02).

4. Discussion

This study explored pedestrian safety at unmarked roadway in China. The main findings are factors related with pedestrian safety and relations of some important factors. Objective measurement is consistent with subjective one on important factors like running frequency and group size, with higher running frequency leading to more danger while larger group size leading to more safety. Pedestrians' higher looking frequency rather than longer duration at vehicles before crossing can improve their safety, but looking behaviors during crossing did not play an important role. Vehicles yield less to young pedestrians but more to stopped pedestrians. In situations where only part of vehicles yield, yielding vehicles can cause danger due to sight blocking of unyielding vehicles beside them. Yielding behavior of pedestrian (going backwards), however is a special interactive behavior at unmarked roadway that increases safety. Different with studies at crosswalks, no gender differences in safety were revealed in the objective measurement but females were considered safer by evaluators. Besides, using cell

[2] This process does not mean to get a model driven by data. The assumed model could have been presented in the introduction part before all the statistical analysis, but it would include many insignificant paths and finally lead to the same model as we presented now. Therefore, we only construct the assumed model after the screen process for simplicity.

Table 3
Correlation matrix of variables.

Gender (XI)	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	XI1	XI2	XI3	XI4	X15	X16	X17	XI8	XI9	X20	X21	X22	x23	x24	x25
Teenage (X2)	.05																								
Young (X3)	.223***	−.20**																							
Middle-age (X4)	.22***	−.21***	−.74***																						
Before_look_freq (X5)	.07	.04	.05	−.04																					
Before_look_dur (X6)	.04	−.03	.05	−.02	.80***																				
Wait (X7)	.04	.03	.01	−.02	.76***	.92***																			
Straight (X8)	.07	.07	−.06	.04	.03	.03	.05																		
Crooked (X9)	−.03	.02	.10	−.10	.04	.03	.02	−.45***																	
Median_time (XI0)	.06	.03	−.01	−.01	−.09	−.05	−.06	−.03	.05																
Near_side_titne (XI1)	−.06	−.09	−.03	.03	.08	.08	.14*	.12	.07	−.08															
Far_side_titne (X12)	−.09	−.06	−.08	.03	.08	.11	.09	.04	18**	−.04	.07														
Run_freq (XI3)	−.11	.02	−.06	.05	−.16**	−19**	−.21***	−.07	−.01	−.04	−13*	−.25***													
Backward (X14)	.03	−.08	−.12	.13*	.13*	.08	.09	.04	.02	−.04	.28	.09	−.01												
Stop Wait (XI5)	.00	−10	−.05	.09	.06	.06	.10	.09	.03	−13*	.78***	.07	−.02	.34***											
Group Size (XI6)	−.03	−.15*	.02	−.04	.16**	.15*	.12*	−.05	−.01	.04	.05	.06	−.02	−.02	.02										
Stops (XI7)	−.09	−.10	−.02	.06	.03	.04	.07	−.01	.03	−15*	.51***	.22***	−.04	.29***	.61***	.05									
Cross_look_freq (XI8)	.12*	−.05	−.10	.09	−.01	−.04	−.06	.02	.07	10	.22***	.15*	−.10	.09	.18**	−.02	.20**								
Cross_look_dur (X19)	.14*	.09	−.06	.01	.03	.02	.04	−.05	.04	15*	.09	−.02	−.09	.11	.13*	−.01	.21***	.40***							
Vehi_change (X20)	.06	.04	−16*	.10	−.05	.00	.00	−.04	−.04	.05	.14*	.11	.08	10	.08	.11	.23***	.02	.11						
Vehi_type (X21)	−.05	−.03	−.05	.00	−11	−.10	−11	−.06	.07	13*	.01	−.04	.03	−.07	−.04	.07	−16**	.06	.08	−.05					
Vehi_flow (X22)	.15*	−.01	−.11	.05	.03	.10	.12	.07	−.03	.10	.08	.10	−.04	18**	.04	.02	.14*	.05	.12*	.11	.07				
Vehi_spd (X23)	.07	.01	−.05	.10	−.02	−.03	−.07	−.08	.01	−18**	−.06	.03	−.04	.02	.05	−.19**	−.02	.08	−.20**	−.23***	−.35***	−.13*			
Ped_spd (X24)	.09	.08	−.05	.08	−08	−.09	−11	.01	−.17**	−.13*	− 43***	−.48***	.25***	−.11	−19**	−15*	−.20**	−18**	−.08	−.13*	−.04	−.09	.16*		
SafetyMargin (X25)	.06	−.11	−.08	.19**	19**	18**	15*	.05	−.03	.04	.02	.00	−15*	.16*	.07	.20**	.00	.02	.08	−.07	.20**	.06	−.06	.07	
SafetyScore (X26)	−.2**	−.04	.22***	−.20**	.15*	.15*	.11	.08	.02	.08	−.04	14*	−.35***	−.10	−.12*	.22***	−.08	−.04	−.04	−.20**	.09	−.06	.02	−.10	.23***

Note: This table does not include distractors-related variables because they resulted in ten dummy variables that will make the table too big to be presented, considering the limited information they conveyed due to small sample size.

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 4
Stepwise regression results with safety margin.

Variables	Coefficients	Std. coefficients	t	p	ΔR^2
(Constant)	1.527		8.49	.000	
Vehile type (vehi_type, bus:1, car:0)	0.41	0.234	4.11	.000	.042
Middle_age[a]	0.327	0.195	3.42	.001	.040
Run frequency (run_freq)	−0.244	−0.175	−2.97	.003	.018
Group size (groupSize)	0.091	0.175	3.02	.003	.025
Crossing speed (cross_spd)	0.382	0.162	2.74	.007	.024
Go backwards (backward)	0.347	0.159	2.75	.006	.018
Looking frequency before cross (before_freq)	0.068	0.157	2.69	.008	.045
Groomed during crossing (cross_groom[a])	0.362	0.143	2.51	.013	.019

[a] Dummy variable. Middle_age is 1 if pedestrian's age falls in [30, 50] otherwise 0. Cross_groom is 1 if a pedestrian groomed *during* crossing otherwise 0.

Table 5
Stepwise regression results with safety score.

Variables	Coefficients	Std. coefficients	t	p	ΔR^2
(Constant)	0.301		2.49	.013	
Run frequency (run_freq)	−0.57	−0.383	−7.14	.000	.125
Group size (groupSize)	0.115	0.207	3.88	.000	.040
Gender (female0, male:1)	−0.339	−0.191	−3.56	.000	.056
Vehicle yield (vehi_yield)	−0.323	−0.183	−3.42	.001	.032
Phone related distractor (before_phone[a])	−0.724	−0.180	−3.34	.001	.027
Eat, drink or smoke during crossing (cross_eat[a])	−0.616	−0.174	−3.28	.001	.030

[a] Dummy variable. Before_phone is 1 if pedestrian used phones *before* crossing otherwise 0. Cross_eat is 1 if a pedestrian eat /smoke *during* crossing otherwise 0.

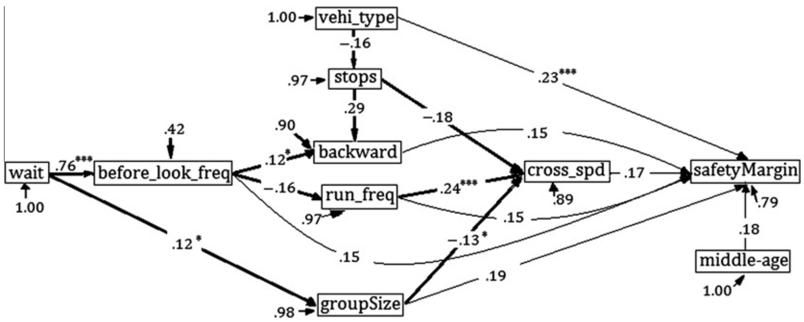

Fig. 3. Path analysis results ($^{*}p < .05$; $^{***}p < .001$; all other paths $p < .01$).

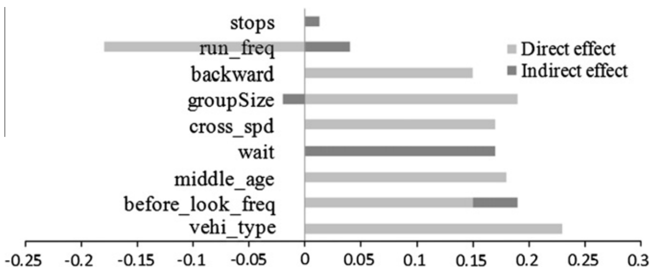

Fig. 4. Direct and indirect effects on safety margin.

phones before crossing, eating while crossing were considered risky. Except the factors related with safety, we found complex relations among some factors. Longer waiting time can increase group size and frequency of looking at vehicles before crossing. The planning nature of looking before crossing made it possible to run less and go backwards more frequently. Larger group size can reduce crossing speed while more frequent running had a contrary effect.

This part first discussed these findings in detail and then made a comparison of two safety measurements. Finally, limitations and future work were addressed, followed by applications of the findings.

4.1. Pedestrian safety factors and their relations

4.1.1. New findings at unmarked roadway

4.1.1.1. Look frequency and duration before and during crossing. Higher frequency of looking before crossing was found to increase safety with more safe behaviors (e.g., lower frequency of running). Two new findings about looking behavior needs to be explained here. One is frequency of looking *before* rather than *during* crossing made the difference. It has been stated in the assumed model that Patla and Vickers (1997) and Geruschat et al. (2003) all found people plan their behaviors before actually carrying them out. A recent study by Holland and Hill (2010) also claimed that people looking left immediately before stepping out could predict traffic situation in the far lane of the road. Therefore, decision making before the crossing seems very important. Perhaps that is why so many studies focusing on the gap acceptance behavior, where pedestrians standing at the curb judging whether it is safe to go (see the review Papadimitriou, Yannis, & Golias, 2009). This planning nature of looking before crossing also made it possible to influence important behaviors during crossing (e.g. behave in safer ways by running less frequently and going backwards more often).

The other finding is *frequency* rather than *duration* of looking before crossing had effect on safety. When collecting data, we observed on the spot some important behavior, which failed to be reflected in the video due to limited scope of the camera. When pedestrians looked at relatively far vehicles, they turned heads frequently with short duration of fixation. However, they looked at near ones in a contrary way (long duration, low frequency). A far vehicle is less dangerous than the near one to pedestrians. The difference in looking behavior may imply that in each looking period, pedestrians judge vehicles' distance and speed, and remembered them while going ahead. To ensure their safety, they look at vehicles frequently to update any changes of the situation and restore it. If the vehicle is far away, this behavior can offer timely information needed. If the vehicle is near, however, even high frequency of looking may fail to offer enough information, so they prefer to keep looking at the vehicles. This mechanism implies that duration of looking only makes sense when pedestrians are worrying about vehicle near them, a situation does not exist before crossing. This would probably explain why duration of looking before crossing failed to have an effect.

4.1.1.2. Running forward, step backward or stand still in interaction. Interaction between pedestrian and vehicle is more prevalent at unmarked roadway. Since it is illegal to cross there, no facilities (e.g. lights) are available to distribute crossing priority. Consequently, pedestrians have to interact with vehicles, like stopping, running and going backwards. Stopping did not emerge to be very important here (small effect mediated by going backward), but running and going backwards did play crucial role in pedestrian safety.

Running during crossing was often used as an index of dangerous crossing based on researchers' assumption (Rosenbloom et al., 2007; Yagil, 2000), rather than objective and quantitative indexes. We went a little further and found lower safety score and smaller safety margin for running pedestrians. Possible explanations are that it gives inadequate reaction time to drivers and it increases the risk of falls. These negative effects overwhelmed its positive effects mediated by higher crossing speed.

Going backwards is rarely reported in previous studies. It is on the observation list because it is a yielding behavior on pedestrians' side (compared with vehi_yield, vehicle-yielding behavior). It was expected to impair safety for being against drivers' expectation and lead to lower crossing speed. However, it is positively related with safety ($r = 0.16$, $p < .05$) but not perceived safety ($p > 0.05$), and only had marginally significant negative correlation with crossing speed ($r = -0.107$, $p = 0.089$). Although these inconsistencies are possibly due to small sample size of pedestrians going backwards, rechecking of the video offered an alternative explanation.

Before the observation, we assumed that pedestrians would first leave a location, and then in case of emergency, go back to original place and try latter. This means that pedestrians may cover the same distance three or more times. In the observation, however, pedestrians did not perform so obvious yielding behavior. When they are standing still waiting for crossing chance, they usually stepped one foot forward aiming for a tentative crossing and meanwhile, looking at the approaching vehicles. If it is not suitable to cross, they pull this foot back. This scene can be proved by the correlation between number of stops and going backward ($r = 0.29$, $p < 0.001$). Maybe this microscopic behavior did not catch our evaluators' attention due to far scope, leading to few changes in the safety score. In real scene, however, it gives the drivers some cues to judge pedestrians' crossing intention. Schmidt and Farber (2009) found at a 10% chance people relied on leg movements to recognize pedestrians crossing intention. This cue made the drivers prepared thus improved safety. The tentativeness can also account for its weak correlation with crossing speed. This hesitation leads to slightly slower crossing speed but it is not like the situation we assumed before, where pedestrians had to cross the same distance back and forth for three trials or more, which would result in slower crossing speed.

4.1.1.3. Gender differences. Males are conventionally regarded as braver than females, and should behave riskier to protect others. Perhaps this gender stereotype can explain why males are more likely to have lower safety score. However, we did not reveal any gender differences in safety margin. Although at signalized crosswalks males were riskier than females with less waiting time before crossing (Hamed, 2001) and more crossings on red (Rosenbloom, 2009). At unmarked roadway, two genders had similar performance on important safety related variables revealed by regression and path analysis (e.g. waiting time ($t_{1/2}(252) = .64$, $p = .53$), before_look_freq ($t_{1/2}(252) = 1.07$, $p = .29$, cross_spd ($t_{1/2}(252) = 1.38$, $p = .17$). These similarities in external behaviors implied similar decision-making process in which both genders have to rely on similar clues like gap between vehicles and their own speed. Compared with risky males at crosswalks, males here are no less careful than females probably because of the greater requirements of judgment efforts at unmarked roadway.

4.1.2. Similar findings

4.1.2.1. Group size. Generally, group size had positive effect on safety margin. Leden (2002) found that pedestrians' risk decreased with increasing pedestrians flows and explained it as increased driver alertness. Larger group size usually resulted in higher pedestrian flow, thus driver alertness could be one reason here. As showed in the correlation analysis, vehicles approach bigger groups with lower speed, which improve safety. Despite its overall positive effect, group size had a negative effect mediated by pedestrians' speed. Murray (2006) used lower walking speed as an index of more risks. He and other researchers (Geruschat et al., 2003) agreed that lower speed put pedestrians in risks with more exposure to dangers. Consistent with previous findings (Gates et al., 2006; Ishaque & Noland, 2008; Knoblauch, Pietrucha, & Nitzburg, 1996), we found large group size reduce crossing speed. One reason could be that, pedestrians in larger groups perceive less danger, so they need not rush to the other side. Another was that pedestrians involved in large groups were usually crossing with friends. They entertained and talked with each other, which reduced their value of time, an important factor that would reduce speed (Ishaque & Noland, 2008).

4.1.2.2. Vehicle types and yielding vehicles. Vehicle type refers to the type of the vehicle producing the final safety margin (selected among six lanes). The site located in the urban area, thus traffics mainly consist of cars and busses. Other vehicle types failed to produce the smallest safety margin in the current observation. Although evaluators did not associate vehicle type with pedestrian safety, buses led to bigger safety margin than cars. This finding is important because in China, low car ownership rate made public transportation system a crucial part. At crosswalks, Hamed (2001) found pedestrians tended to end their waiting to make crossing attempts when the oncoming vehicle was a bus. This fact indirectly confirmed our finding at unmarked roadway. Possible explanation is that buses usually have lower speed than cars, as revealed by a negative correlation between vehicles speed and vehicle type.

Vehicles are more likely to yield to stopped pedestrians but less to young pedestrians. It is possible that stopped pedestrians were given priority because of the cues of crossing intention mentioned above (previous section on "going backward"). The young pedestrians, however, are capable of crossing and are not on the list of "favor receivers", usually including the elderly and children as required by social norms.

It is interesting that evaluators perceive more danger when vehicles yield. This may be due to a "multiple threats" situation where a driver in one lane (the first encountered in the crossing direction) yielded while a driver in the adjacent lane of the same direction of travel (the next encountered) did not yield (Mitman, Ragland, & Zegeer, 2008). In this case, after pedestrians had crossed the yielding vehicle lane successfully, they may be struck by the unyielding vehicles just arrived.

4.2. Comparison of perceived safety and safety margin

Pedestrians' safety margin and evaluators' rated safety score have significant positive correlation. They are also consistent in two important factors (run frequency and group size): more running related with danger while bigger group size related with safety. In addition, no significant factors in the two safety indexes had effects in contrary directions. The consistency between the two safety measurements showed that people could perceive safety rather accurately, perhaps due to biological requirements of survival. With this ability, they can cross more safely and can guide other pedestrians (e.g. help friends and kids). However, there laid differences under the general consistencies. Safety margin focused on absolute safety of crossing, but it did not care about potential dangers. For instance, yielding vehicles could be dangerous because of unyielding ones beside them. However, as safety margin only measured the vehicle most likely to cause accidents, it could not capture multiple threat situations. Perceived safety, on the other hand, could reflect pedestrian safety very comprehensively considering almost all available clues. However, evaluators could not capture unobvious clues and they were inevitably influenced by stereotypes. For instance, pedestrians' speed was not easy to perceive and males were evaluated riskier. To integrate the two measurements, safety margin should act as a major index while perceived safety could offer more information or cues neglected by safety margin but reflected real situations after rechecking.

4.3. Limitations and future work

This study has several limitations to be addressed in future works. First, pedestrians in certain groups (e.g. eating pedestrians) were not frequently observed, so we cannot generalize much about them. Second, some potentially important information about the environment and pedestrians' behaviors were not recorded because of field setting. For example, researches have shown that pedestrians may make crossing decisions based on distance of vehicles (Oxley, Ihsen, Fildes, Charlton, & Day, 2005; Tung et al., 2008), but we cannot capture information of vehicles faraway because of camera scope (if we zoom out to cover vehicle behavior, pedestrian behavior cannot be observed clearly). Third, we made several simplifications during the coding process. For instance, the duration of looking at vehicles was measured by head movement time.

Moreover, behavioral orientation of the study made it inevitable that only some objective factors were considered while psychological aspect (e.g. judging ability, tense) is neglected. Accordingly, the goodness-of-fit of the regressions are not that satisfying (adjusted $R^2 \leqslant 0.29$). The complexity of the real crossing environment may have aggravated the situation. For example, in a pedestrian mid-block crossing difficulty evaluation study, Chu and Baltes (2001) built several linear regression models with large sample size (767) but the highest adjusted R^2 equaled only 0.35.

4.4. Applications of the current results

The findings above suggest several applications on development of intelligent warning systems, further study of pedestrian safety, and skill trainings for both drivers and pedestrians. Current intelligent pedestrian detection systems mainly detect whether there were pedestrians present and track their movements on crosswalks. They aimed to activate pedestrian green lights at pedestrians' arrival and cancel the normal "walk" phase, thus reducing delay for crossing traffic (Huang & Zegeer, 2000). At unmarked roadway, however, such a facility seemed to go against the law of vehicle priority and it stopped vehicles whenever pedestrians arrived (false alarms if pedestrian are obviously safe). Instead, detectors can be installed at frequently used crossing area detecting pedestrians' behaviors. If crossing pedestrians were likely to have very small safety margins, then the detector can send a warning to the pedestrians and drivers, otherwise leave the pedestrians alone. This warning system is a compromise of traffic efficiency and pedestrian safety.

The findings can also facilitate further works about pedestrian behavior. First, pedestrian modeling works aimed for safety can put more emphasis on important factors like running frequency, looking frequency before crossing, group size and so on. Second, our findings suggested that experimental works in virtual environment should consider the arrival pattern of pedestrian rather than only allow one person to cross at a time. Longer waiting time resulted in bigger group size that can improve safety in real context, not just loss of crossing chance in virtual environment studies (Neider et al., 2009). Finally, we found general consistency perceived safety and safety margin. Their mutual confirmation implied their effectiveness to show pedestrians' safety and possibility to replace one with the other in case of ill measurement or seeking easy measurement in some situations.

As for the crossing skills training and education for pedestrians, if they happen to cross at unmarked roadway, there are several points need to be paid attention. For example, pedestrians should wait there for other crossing pedestrians to form a larger group and look at vehicles before crossing frequently instead of fixing on certain vehicles. During crossing, they should cross quickly but not run. Make tentative crossings (e.g. step forward and go backwards) is recommended to inform crossing intentions to drivers. Gender stereotypes should also be noted. Females are no safer than males, so they should also display as many cautious behaviors. Since vehicle yielding rate at unmarked roadway in China is not that high (48.8%), pedestrian should check vehicles beside the ones yielded to them before rushing forward. On drivers' side, if they find that vehicles beside them have obviously reduced speeds, they should slow down to see whether there are pedestrians crossing.

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