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Pedestrians' crossing behaviors and safety at unmarked roadway in China

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ABSTRACT

Pedestrians' crossing out of crosswalks (unmarked roadway) contributed to many traffic accidents, but existing pedestrian studies mainly focus on crosswalk crossing in developed countries specifically. Field observation of 254 pedestrians at unmarked roadway in China showed that 65.7% of them did not look for vehicles after arriving at the curb. Those who did look and pay attention to the traffic did so for duration of time that followed an exponential distribution. Pedestrians preferred crossing actively in tentative ways rather than waiting passively. The waiting time at the curb, at the median, and at the roadway all followed exponential distributions. During crossing, all pedestrians looked at the oncoming vehicles. When interacting with these vehicles, 31.9% of them ran and 11.4% stepped backwards. Running pedestrians usually began running at the borderline rather than within the lanes. Pedestrians preferred safe to short paths and they crossed second half of the road with significantly higher speed. These behavioral patterns were rechecked at an additional site with 105 pedestrians and the results showed much accordance. In terms of safety, pedestrians who were middle aged, involved in bigger groups, looked at vehicles more often before crossing or interacted with buses rather than cars were safer while those running were more dangerous. Potential applications of these findings, including building accurate simulation models of pedestrians and education of drivers and pedestrians in developing countries were also discussed.

1. Introduction

1.1. Unmarked roadway crossing

As a developing country, China has high numbers of traffic accidents and pedestrian deaths compared with those in developed countries. In 2004, there was a total of 107,077 traffic deaths and 480,864 injuries (CRTASR, 2005). Both drivers and pedestrians contribute to this severe problem. However, many previous studies focused on the driver's side (Wang and Li, 1995; Liu et al., 2009; Wu et al., 2009) rather than the pedestrian side. According to CRTASR (2005), pedestrians illegally crossing through the roadway leads to 11,383 accidents, accounting for 83.25% of the total number of accidents caused by pedestrians. By the law in China, if there is no overpass or underpass, pedestrians should only cross at signalized or marked crosswalks unless there are no such facilities. Therefore, "illegally crossing through the roadway," means that pedestrians do not cross at crosswalks (cross at unmarked roadway). Our preliminary study consisted of two focus groups (12 participants) and revealed that this would happen under the following conditions: pedestrians have urgent tasks, when the road situation satisfies their personal safety requirements, when there are no crosswalks nearby, and when the pedestrians are ignorant of the traffic regulations. Since these occasions happen frequently and the consequences of the resulting accidents are rather serious, unmarked roadway crossing became the focus of this study.

On the one hand, unmarked roadway crossing has received insufficient attention in research worldwide. As of today, researches concerning pedestrian crossing behaviors were taken in both virtual and real roads. In virtual road crossing studies (e.g. Cavallo et al., 2009; Lobjois and Cavallo, 2009), researchers mainly investigated pedestrians' judgments before crossing, regardless of the presence of crosswalks. Studies that were done utilizing real life roads were mainly conducted at both signalized crosswalks (Hatfield and Murphy, 2007; Tiwari et al., 2007; Rosenbloom, 2009) and marked or unmarked crosswalks (Ragland et al., 2007; Rosenbloom et al., 2008). Unmarked roadway crossing was underreported and for the most part the reported ones primarily did not focus on unmarked roadways itself. For instance, when building the pedestrian crossing behavior model, Airault & Espié (2005) illustrated whether pedestrians would cross at or out of crosswalks as a simplified example to show a pedestrian's tendency to choose among the available facilities. Through evaluation, Chu & Baltes (2001) discovered that pedestrians evaluated crossing through roadway to be more difficult than at crosswalks. In their studies, roadway crossing was only one condition out of a set of variables to be evaluated.

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On the other hand, unmarked roadway crossing may have different characteristics with other facilities in question. Researchers showed that compared with marked crosswalks, pedestrians at unmarked crosswalks were more likely to look in both directions, wait in the street instead of on the curb, and run across the road when they felt they had the chance (Mitman et al., 2008). This decrease in protection and control of the activity at these crosswalks, resulted in several differences in crossing behaviors. Therefore, it is likely that when pedestrians are under less control than at unmarked crosswalks, say unmarked roadway, they will also behave differently. In fact, the focus group also found that pedestrians perceived less tense at crosswalks where they had the right of way. What's more interesting, is that they tended to watch for vehicles more frequently, walk more quickly or even run across unmarked roadway.

To make the topic more focused, this study only addressed unmarked roadway crossing in China. Chinese people complete 40% of their travelling by walking (Yang et al., 2006), which exposes them to a considerable amount of danger. Fortunately, efforts have been made to study pedestrians delay (Li et al., 2005), red light running (Yang et al., 2006) and the intention of pedestrians to cross at potentially unsafe situations (Zhou et al., 2009). However, despite these efforts, little research has been addressed to the illegal unmarked roadway crossing issues in China.

1.2. Pedestrians crossing behaviors

Pedestrians cross roads at different locations. In terms of protection, crossing facilities follow the order of underpass or overpass, signalized crosswalks, marked but not signalized crosswalks, unmarked crosswalks and unmarked roadway. Unmarked roadway differs from an unmarked crosswalk in that the latter refers to unpainted crosswalks at intersections while the former is unpainted midblock locations. In fact, unmarked roadways can hardly be called a crossing facility, as there is no protection at all. However, since all crossings share some basic processes, studies at other facilities were introduced to provide the target components of crossing behaviors at unmarked roadways.

First, pedestrians' crossing behaviors are related with their characteristics (e.g. age and gender). At signalized crosswalks, females wait longer than males (Tiwari et al., 2007). At marked crosswalks, the older the pedestrian is, the longer the waiting time will be (Hamed, 2001). This implies that age and gender may be important factors at unmarked roadway crossing. Second, pedestrians have to judge the situation to find a proper chance to cross. The study of this judging process was governed by gap acceptance theory (Brewer et al., 2006). That is, pedestrians look to determine whether the gap between two vehicles is big enough to cross. If yes, then the gap is accepted and the person will cross, otherwise the civilian will wait for better opportunities. Consistently looking at vehicles before crossing was the most frequently mentioned safe behavior that was practiced by the focus group participants. This suggested behaviors like waiting and looking at vehicles might make a difference. Finally, the manner in which the pedestrians cross the road also affects their safety. Running was considered dangerous at marked crosswalks (Rosenbloom et al., 2008). Low crossing speed (Murray, 2006) and using a cell phone (Hatfield and Murphy, 2007) also impaired pedestrians' safety. In accordance with these findings at crosswalks, the focus group gave evidence that pedestrians at unmarked roadways regarded running and being distracted as unsafe conducts, while the estimation of one's own speed was considered necessary in judgments. As an interactive behavior specific to the unmarked roadway, going backwards was not covered in previous studies. However, focus group participants considered it dangerous because it went against the expectations of the driver. These results encouraged inclusion of distractors, running, going backwards and the crossing speed in this unmarked roadway study. In addition, participants thought of police cars and big trucks as being dangerous and they were divided on the safety of buses. Despite the small sample size of the focus group, these results urged us to include vehicle type as another factor when considering safety issues.

In summary, this study aims to explore pedestrian behavior and safety at unmarked roadway in China. The behavioral patterns could promote further modeling researches, and the discussion about safety is expected to improve pedestrian safety in some way.

2. Methods

2.1. Location

Illegally crossing through unmarked roadways often happens when attractions (i.e. places where many pedestrians visit) exist on either side of the road. For example, on one side of the road, there may stand big supermarkets or a large plaza area with restaurants, and on the other side there might be residential blocks and bus stations where crowds of people gather. People naturally hope to reach their destinations quickly, so they are not likely to make a detour and cross at a crosswalk nearby. For this case, a site that is representative of this situation and at the same time efficient for data collection was chosen.

The observation site is near the North Bus Station of Hangzhou, China. It is a busy site with about 2826 vehicles and 757 pedestrians passing through every hour. This two-way road has three lanes on each side. Although it's only 82 m away from the nearest zebra crossing, most people choose to cross here for convenience. Fig. 1a is a simple sketch of it. This site was chosen because it is a typical unmarked roadway-crossing site in Hangzhou. Other common variations of it can be seen in Fig. 1b.

2.2. Field work

Two synchronized cameras were set on two sides of the crossing area ("virtual crosswalks") to take videos there. One camera was set on a high building near the area to get a bird's-eye view of the site, while the other was placed 1.6 m above the ground to capture details of pedestrian behaviors, especially their head movements. The video shooting started from 10 AM and lasted until noon on October 14th, and from noon until 4 PM on November 17th. Vehicle volumes were not different between the two days (χ^2 (1) = 0.90, p = .344). Both days were sunny and nothing special happened.

2.3. Video data coding

The video was played in Adobe Premiere Pro CS4 version 4.0.1 to perform the frame by frame coding with a time display accuracy of 0.04 s. The coding was carried out in the following two steps manually.

2.3.1. Select pedestrians

The first step aimed to make sure the selected pedestrians are crossing in normal conditions[1] and can be observed clearly. Therefore, we neglected pedestrians belonging to the following categories: Crossing on foot with a bicycle or motor, vehicles showing up 6 s after pedestrians had finished crossing one lane (for all lanes), people who crossed while staying in a very large group exceeding

[1] Pedestrian safety at unmarked roadway are usually threatened when there were oncoming vehicles with normal speed. Therefore, study of this situation was most meaningful and it should be considered as the "normal condition".

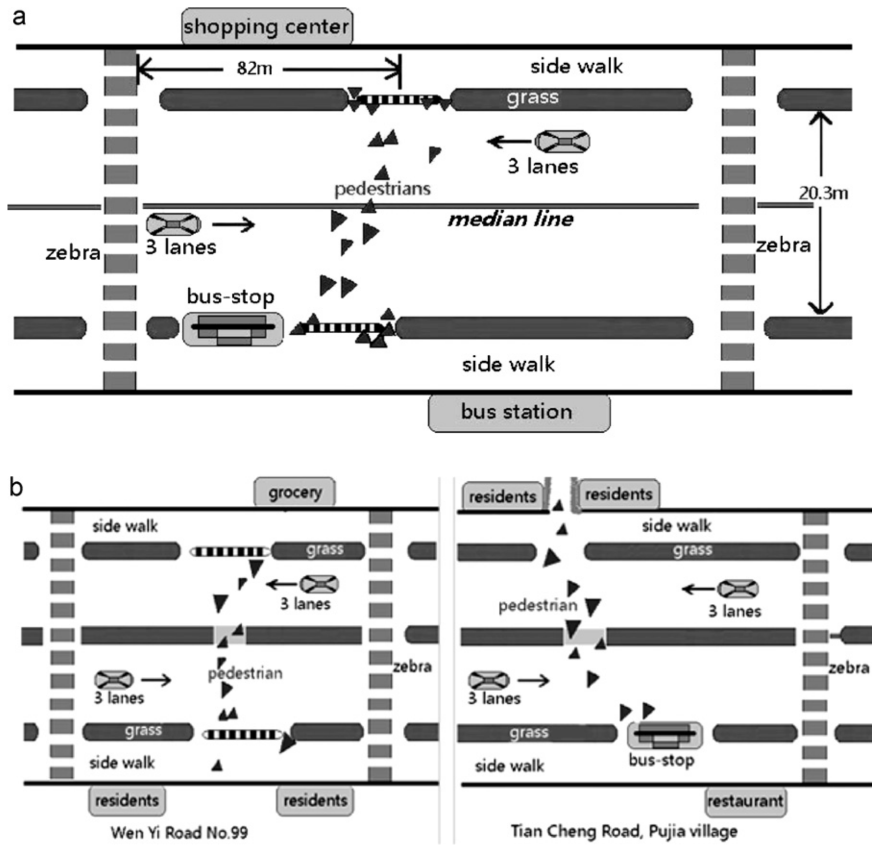

Fig. 1. (a) Sketch of the site, (b) Common variations of our research site.

12, crossing in the gaps between the lines of stopped vehicles (traffic jam) or those who cannot be seen clearly at any moment after arrival.

2.3.2. Coding the variables

Table 1 shows the variables coded and their coding methods.

Fig. 2 shows coding of crossing styles. If pedestrians coincidentally arrived at a point right straight toward their destination (e.g. C start, D destination), they could follow shortest and safest path, which was coded as Style 0. If they were not so lucky to arrive at such points (e.g. A start, B destination), they ended up suffering higher risks. In that case, if a pedestrian's path was roughly the shortest possible path but was not the safest (go straight ahead to destination), then it would be the short distance style (Style 1). In contrast, if pedestrians yielded to vehicles by walking along the lane to wait for a better crossing chance, they would have a curved path, which would be a safe style (Style 2). This can also be a combination of the three examples shown in Fig. 2. That is, pedestrians can change their directions at any of the lanes, regardless of whether it is the median line or not.

To simplify the coding results, pedestrians susceptible to multiple distractions were coded with the most influencing distractor (assessed by our researchers according to experience). The order of influences is: phone related distractor, talking, eating or smoking, carrying stuff and grooming. However, this had little influence on the results, as only very few had multiple distractors. For the distraction of carrying something, pedestrians had to be seen holding things that have influence on their behavior, e.g. luggage. For "Eating", pedestrians must have food in their hands and they must be consuming the food. "Grooming" means the act of pedestrians sprucing and combing their hairs. Group size is the number of people crossing together, regardless of whether they know each other or not. We coded it in two steps. In the first half, if pedestrian X had crossed more than 50 percent of half of the road width before pedestrian Y began crossing (same or contrary direction), then they were not in a group. Otherwise, they belonged to one group. Then the far side group size was counted in the same way. The final group size is average of the two. For before_look_freq, before_look_dur, cross_look_freq and cross_look_dur, a noticeable turn of the head needs to be seen (similar to Bungum et al., 2005). Note that cross_look_dur is the ratio of the duration of looking left to right and total crossing time (exclude median_time and stopWait_time). Since pedestrians did not have the same crossing time, this procedure made it possible to compare cross_look_dur among pedestrians.

3. Results

The results cover three parts. First, descriptive findings were presented to have a general knowledge of the observation. Second, analysis of some important behavioral patterns was conducted. Finally, a multiple regression was used to explore factors related with pedestrian safety margin.

3.1. Descriptive findings

Overall, 254 pedestrians were coded and analyzed. Table 2 presents descriptives of the variables. All the time related variables is measured in seconds and cross_spd is measured in meters per second.

Before crossing, 64.6% of the pedestrians went directly to the street without waiting. Among those who waited, 96.7% looked left and right to analyze the situation. Overall, it is important to find that 65.7% of the pedestrians did not look to check for oncoming

Table 1
Definitions of variables coded.

Variables	How to code
Gender	Male: 1, female: 0
Age	Teenage:<20, young:[20,30], middle: [30,50], elderly >50
Before_distractor	No distractor: 0, carry:1, eat/drink/smoke: 2, phone: 3, groom: 4, talk: 5
Cross_distractor	No distractor: 0, carry: 1, eat/drink/smoke: 2, phone: 3, groom: 4, talk: 5
Styles	Safe: 2, short distance: 1, no distinction: 0
Before_look_freq	Frequency of looking at vehicles before crossing; count head movements
Before_look_dur	Measure duration of looking left and right before crossing
Run_freq	Count how many times pedestrian run
backward	Count how many times pedestrian go backwards
Change_direc	Number of direction changes during crossing
GroupSize	Number of pedestrians crossing together in both directions
Wait	Time spent before crossing after arrival at the site
Cross_look_freq	Frequency of watching for vehicles; count head movements
Cross_look_dur	Time of looking left and right/cross time (exclude median_time and stopWait_time)
Median_time	Time spent on the median line (the line in the middle of two-way roads)
Near_side_time	Time spent at the starting half of the road
Far_side_time	Time spent at the ending half of the road
Not_look_time	Time of not looking at vehicles at last part of crossing
Stops	Count the number of stops (hesitate for >0.04 s) during crossing
StopWait_time	Time duration of standstill in all stops
Ped_spd	Distance/cross time (exclude median_time and stopWait_time)
safetyMargin	Gap between the time a pedestrian crosses before a vehicle and the time it arrives at the crossing point
Vehi_type	The type of the vehicle yielded safetyMargin[a]: bus: 1, car: 2

[a] Since the observation was conducted in urban area with few trucks, the vehicle observed to yield the safety margin were buses or cars.

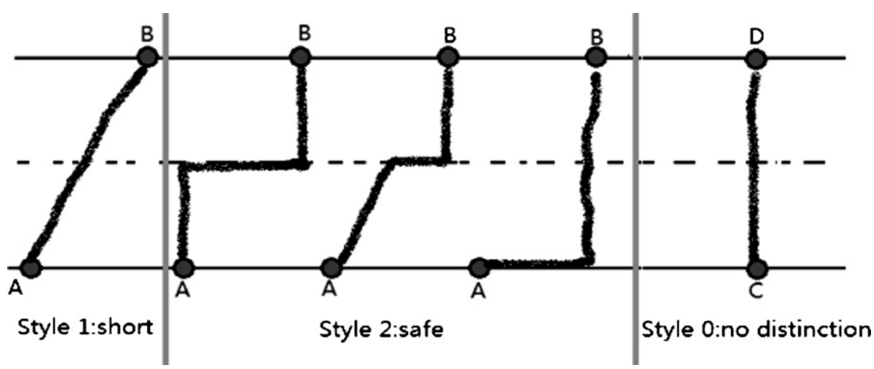

Fig. 2. Crossing styles coding. Pedestrians arriving at A with destination of B adopt Style 1 (shortest distance between A and B) or 2 (safer but longer than Style 1). Pedestrians arriving at C with destination of D adopt Style 0.

vehicles before crossing the road. During crossing, all pedestrians looked for vehicles. They made tentative crossing, as 40.6% stopped (not at the median line), stepped backwards (11.4%), or ran (32.9%) if they got the chance. When they reached the median line, 28% of the pedestrians would stop and check the situation again in a way similar to when they were standing at the curb.

3.2. *Behavioral patterns*

The above part gives a simple description of the observational results. This part conducted further analysis about behavioral patterns of pedestrians. First, pedestrian safety was analyzed through crossing styles. Then crossing behaviors were compared in terms of waiting time, distractors, crossing speed, running and looking at vehicles.

3.2.1. *Crossing styles*

Pedestrians (28.0%) adopted Style 0 (safe and short, see Fig. 2) if their arriving point was straight toward their destinations (pedestrians need not compromise between safety and distance in this situation). For the 72% remaining, 83.6% adopted a safe style (See Style 2 in Fig. 2) while only 16.4% adopted the short one (See Style 1 in Fig. 2). The difference in proportion was significant (χ^2 (1) = 82.7, p < .001). Since adopting a safe style meant that the pedestrian had to use curved paths covering longer distances than that of the short style, the apparent preference over this “unwise choice” suggested a safe tendency.

3.2.2. *Waiting behavior in crossing*

Pedestrians may wait in three situations. These include waiting for a chance to go before crossing (35.4%), stopping and waiting in the roadway (40.6%), and stopping and waiting at the median line (28%). These waiting behaviors are quite similar in terms of waiting duration. Fig. 3 shows the distribution of wait time duration for those waited. All the waiting times followed *exponential distributions*[2]. Time spent at the median line followed an exponential distribution with $\lambda = 0.15$, $\gamma = 1.0$ (χ^2 (5) = 5.73, p = .33). For waiting time at the curb, $\lambda = 0.14$, $\gamma = 0.5$ (χ^2 (6) = 1.47, p = .96). Stop and wait time (standstill) followed a one parameter exponential distribution with $\lambda = 0.19$ (χ^2 (6) = 3.89, p = .69). The distributions suggest that most pedestrians who waited behaved similarly in each waiting period. They did not wait for a long time before starting to cross again.

[2] Trial version of “EasyFit 5.3” of Mathwave Company was used to generate this distribution and the distributions in the following part of the paper. Probability density function of exponential distribution: $f(x) = \lambda \exp(-\lambda(x-\gamma))$.

Table 2
Descriptive statistics.

Discrete variable	Level	N	Percent	Continuous variable	Mean	Std. dev.
Gender	Female	118	46.5	Wait	2.8	5.47
	Male	136	53.5	Before_look_freq	1.1	1.94
Age	Teenage	14	5.5	Before_look_dur	2.3	4.72
	Young	104	40.9	Median_time	2.6	6.32
	Middle	112	44.1	Near_side_time	14	6.84
	Elderly	24	9.5	Far_side_time	11.6	3.97
Styles	No distinction	71	28	StopWait_time	2.1	4.32
	Short	30	11.8	Change_direc	1.5	1.22
	Safe	153	60.2	GroupSize	2.8	1.57
Stops	0	151	59.4	Cross_look_freq	5.4	2.42
	1	74	29.1	Cross_look_dur	0.6	0.21
	2	23	9.1	Not_look_time	6	3.83
	3	5	2	Cross_spd	1	0.35
	4	1	0.4	safetyMargin	2.5	0.83
Run_freq	0	173	68.1			
	1	66	26			
	2	15	5.5			
Backward	0	225	88.6			
	1	25	9.8			
	2	4	1.6			
Vehi_type	Bus	86	33.9			
	Car	168	66.1			
Before_distractor	No	148	58.3			
	Carry	38	15			
	Eat/drink/smoke	15	5.9			
	Phone	13	5.1			
	Groom	12	4.7			
	Talk	17	6.7			
Cross_distractor	No	129	50.8			
	Carry	37	14.6			
	Eat/drink/smoke	17	6.7			
	Phone	12	4.7			
	Groom	31	12.2			
	Talk	9	3.5			

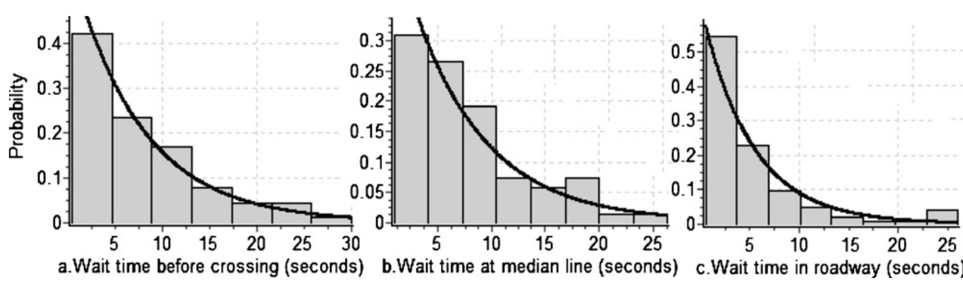

Fig. 3. Wait time in crossing and their distributions (for pedestrians waited).

3.2.3. Change of distractors before and during crossing

Overall, 41.7% of the pedestrians had distractors (including using a cellular phone, talking with others, carrying luggage, and grooming) present before crossing. This ratio changed slightly to 49.2% during crossing. The detailed changes are shown in Fig. 4. Numbers in the bar represent number of pedestrians with corresponding distractors.

Surprisingly, pedestrians significantly increased the chance of grooming behavior after they started crossing (χ^2 (1) = 8.4, p < .01). Nevertheless, talking with other people decreased from 17 to 9 after beginning to cross; however, this decrease did not prove significant (χ^2 (1) = 0.013, p = .117). Moreover, pedestrians carrying stuff (χ^2 (1) = 2.5, p = .904), using cell phones (χ^2 (1) = 0.04, p = .841) and eating or smoking (χ^2 (1) = 0.125, p = .724) did not change a lot while crossing.

3.2.4. Running behavior

Fig. 5 shows the numbers of lanes pedestrians had crossed when they began to run (see Fig. 6 for illustration of the related concepts).

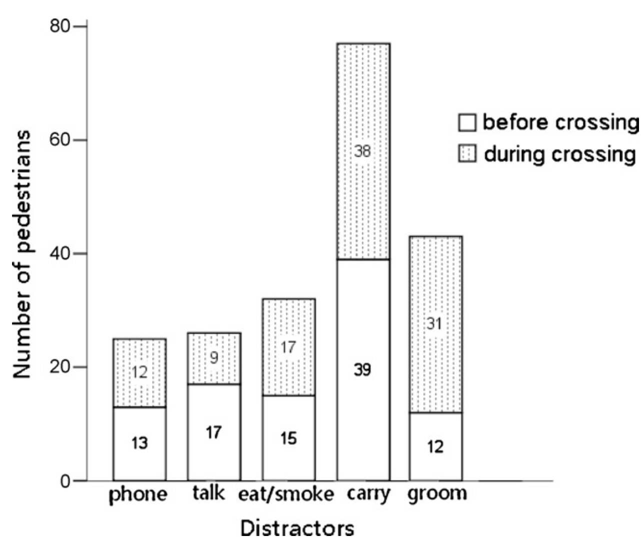

Fig. 4. Distractors before and during crossing.

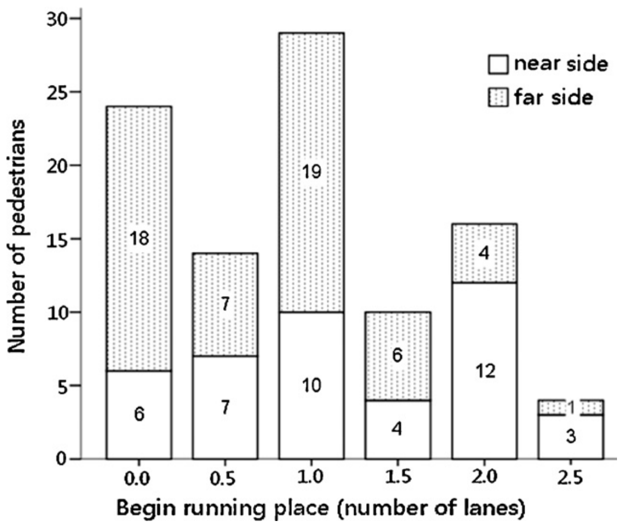

Fig. 5. Begin running place of the pedestrians.

Pedestrians had a higher chance to run at borderlines between lanes rather than within the lane (χ^2 (1) = 17.3, p < .001).

More pedestrians ran in the far side than the near side (42 vs. 55), but this also failed to be significant (χ^2 (1) = 1.7, p = .187). However, their beginning running position was located more commonly in the median-far places (see Fig. 6, "*more running*"). More specifically, when crossing the first two lanes (from Lane 0.0 to 2.0 of both near and far sides), more pedestrians ran in the far side (χ^2 (1) = 6.9, p < .01). When they were crossing the last lane of both near and far sides however, more running pedestrians were observed at the last lane of the near side than that of the far side (χ^2 (1) = 5.0, p < .05).

3.2.5. Crossing time of near and far side

The differences of the near and far side do not just exist in pedestrians running during crossing. Take the whole sample for analysis, the best-fit linear regression line of time spent on two sides is far_side_time = 0.04 × near_side_time + 11.0 (F (1, 252) = 1.20, p = .274). This slope and intercept indicates that pedestrians did not spend the same amount of time at the two different sides. A T-test (two-tailed) shows that far_side_time was much lower than near_side_time (t (253) = 5.01, p < .001).

3.2.6. Looking behavior

Due to field setting, the looking behavior was measured by head movement, which was signified by noticeable movements of the chin (Bungum et al., 2005). Fig. 7 displays distribution of before_look_dur and cross_look_dur for those who looked. The former fits well with the *exponential distribution* (λ = 0.16, γ = 0.4, χ^2 (6) = 2.45, p = .87) while the latter follows more closely with the *Dagum distribution*[3] (k = 0.18, α = 14.46, β = 0.88, γ = −0.04; χ^2 (7) = 5.53, p = .59). The distributions suggest that pedestrians prefer engaging in the checking process during crossing rather than right before crossing. They checked to see the vehicles simply for a short time right before crossing. During crossing, however, they spent a considerable amount of time looking left and right, which nearly occupied 70% of their crossing time.

Table 3
Multiple regression on safetyMargin (log transformed).

Variables	Coefficient	Std. err	β	t	p
Vehi_type	0.16	0.04	0.23	4.08	0.000
Middle_age	0.14	0.04	0.22	3.72	0.000
GroupSize	0.03	0.01	0.16	2.72	0.007
Ped_spd	0.14	0.06	0.15	2.55	0.011
Run_freq	−0.08	0.03	−0.15	−2.59	0.010
Before_look_freq	0.02	0.01	0.14	2.28	0.024
Backward	0.12	0.05	0.14	2.42	0.016
Groom	0.12	0.06	0.12	2.09	0.038
Constant	0.5	0.07		6.93	0.000

3.3. Safety margin analysis

The safety margin is the difference between the time a pedestrian takes to cross the traffic and the time the next vehicle arrives at the crossing point (Chu and Baltes, 2001). Compared with crash data that only represented pedestrians' safety in accidents that already happened, the safety margin can be obtained whenever a pedestrian crosses the road, with smaller safety margin for pedestrians under potentially more dangerous situations. In other words, the safety margin can represent a pedestrian's relative safety in a predictive way that deserves its measurement and discussion in this study.

Log normal distribution[4] (σ = 0.30, μ = 0.96, γ = −0.23) was found to fit the collected data (χ^2 (7) = 4.12, p = .76). To avoid narrow misses, which may result in due to unexpected events (e.g. fall down), the margin of safety was required to be more than 1.5 s (Simpson et al., 2003). Given an average crossing speed of 1.0 m/s (see Table 2), this interval provides 1.5 m of safety distance without braking on the drivers' side. In our observation, most pedestrians had greater safety margins but 7.9% of them failed to meet this basic safety requirement. To standardize margin of safety, it was transformed by a natural log function. Then, a multiple regression was conducted to screen the possibility of important predictors of safety. The candidate predictors come from all the variables in Table 2 except for safety margin. The results are presented in Table 3.

The variables in Table 3 are variables emerging as significant predictors. They have significant linear relationships with the margin of safety (F (8, 245) = 8.09, p < .001) and can explain 21% of the total variance (adjusted R^2 = .18). For all significant factors, no severe multicollinearity exists (minimum tolerance = .90).

Among these variables, vehicle type (vehi_type, highest std. coefficient) is the most important predictor. Pedestrians had lower safety margins when the oncoming vehicle was a car than a large bus. The higher frequency pedestrians looked left and right before the crossing, the safer they were. Similar outcomes were also true for those who went backwards. If pedestrians were not middle-aged, walked slowly and involved in smaller groups, they were in more danger. Further similarities exist for those who decided to settle their hair or clothes during crossing. Among all of the variables in Table 3, only running frequency (run_freq) had a negative effect (std. coefficient =–.150, p = .01), suggesting less safety for running pedestrians.

3.4. Enhancement of major findings: the second unmarked crossing site

As shown in previous parts, the major findings of this study are the patterns of pedestrian crossing behaviors. To ensure

[3] Distribution Probability density function of Dagum distribution: $f(x) = \exp\left(-\frac{1}{2}\left((\ln(x-\gamma)-\mu)/\sigma\right)^2\right) / \left(\sigma\sqrt{2\pi}(x-\gamma)\right)$.

[4] Probability density function of log-normal distribution: $f(x) = \exp(-1/2 (\ln(x-\gamma)-\mu)/\sigma^2)/(x-\gamma)\sigma\sqrt{2\pi}$.

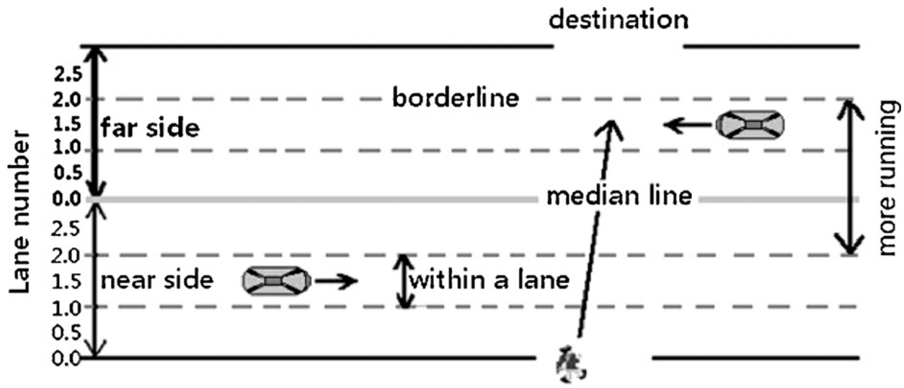

Fig. 6. Illustration of the roadway related concepts.

the generalization of the main findings, Wenyi Road in Fig. 1b was also chosen as a complementary site (105 pedestrians). The differences between the Wenyi Road and the North bus station are mainly: (1) the original site (Fig. 1a) had no crossing constraints near the median line (i.e. there were no physical objects on the median line constraining their paths), in contrast to Wenyi Road, which had constraints (e.g. trees, bushes etc.) on the median of the road. (2) The median of the original site is not raised and the median line is narrow (width was less than 0.3 m), vs. the Wenyi Road, which has a raised median wider than 2 m. These physical differences of the two sites may lead to slight differences in the findings of pedestrian behavioral patterns.

3.4.1. Crossing styles

After considering the additional site, it was found that if there are existing crossing constraints (e.g. trees, bushes, or fences), pedestrians had to adjust their crossing route. This path went through or bypassed these constraints, so the crossing styles cannot be compared.

3.4.2. Waiting behavior at roadside, in roadway and at median

Waiting time at the roadside followed exponential distributions (χ^2 (2) = 1.92, p = .383, λ = 0.11) and the waiting time in the roadway followed this same distribution (p = .48, λ = 0.16). However, since the site had a raised median and the pedestrians usually stop and wait at different positions, their waiting time at the median was coded as the total time spent on the median. It did not follow an exponential distribution (χ^2 (5) = 17.3, p = .004). In general, the waiting time data was similar to that of the original site, except for the median wait time.

3.4.3. Change of distractors before and during crossing

Distractors were analyzed but were not emphasized much because of the small sample size of pedestrians having specific distractors. The only difference between these distractors, before and during crossing, was the increase of grooming behavior (referred to as combing their hairs or sprucing). In the additional site, the data showed similar tendencies with the previous site (Pedestrians with other distractors almost did not change while grooming pedestrians increased from zero to six after they started crossing).

3.4.4. Running behavior

At the additional site, 31 starting running positions were observed. Thirteen of them were within the lanes and the rest of the 18 were at the borderline. These results still showed a preference over borderline.

3.4.5. Crossing time of near and far side

Crossing time in the far side was far less than the near side. The linear regression equation was $far\_side\_time = 0.032 \times near\_side\_time + 9.35$, $F(1,103) = 0.47$, p = .495. This was quite different from $far\_side\_time = near\_side\_time$. A two tailed t-test showed that far side time was much shorter than near side time (t (104) = 2.10, p = .039). This was consistent with our finding at the original site.

3.4.6. Looking behavior before and during crossing

At the original site, the durations of looking behavior (before_look_dur) followed an exponential distribution, while the proportion of looking during crossing (cross_look_dur) followed a Dagum distribution. At the additional site, the results were consistent with those of the original site. “Before_look_dur” followed an exponential distribution (χ^2 (3) = 1.35, p = .716; λ = 0.11). “Cross_look_dur” followed a Dagum distribution (χ^2 (6) = 2.74,

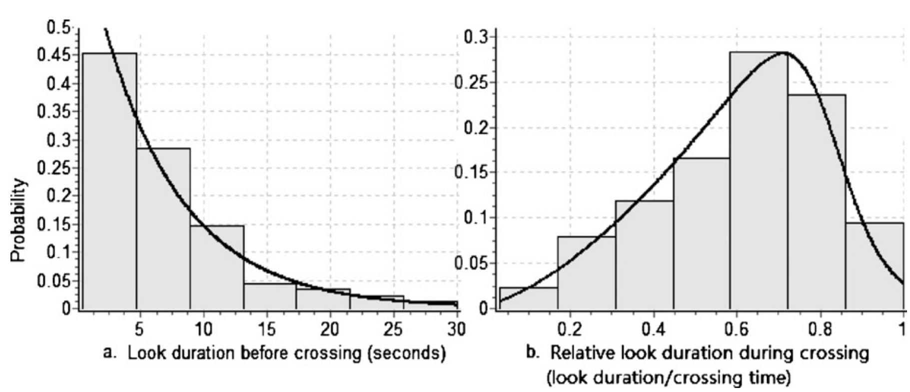

Fig. 7. Duration of looking behavior before and during crossing.

Table 4
Consistency between two sites' major findings.

Behavior patterns	Consistency
Crossing styles	Not consistent due to crossing constraint
Waiting time at median	Not consistent due to raised median
Waiting time at roadside	Yes
Waiting time in roadway	Yes
Distractor change	Yes
Running behavior	Yes
Near and far side crossing time	Yes
Looking duration before crossing	Yes
Looking behavior during crossing	Yes
Safety margin	Yes

$p = .841$; $k = 0.21$, $\alpha = 6.8$, $\beta = 0.60$). This meant that the findings regarding looking behavior were consistent.

3.4.7. Distribution of safety margin

Safety margin followed a log normal distribution in the original site. The additional site's safety margin was also fitted with EasyFit 3.5. The results showed that it also followed a log normal distribution (χ^2 (6) = 2.10, $p = .531$; $\sigma = 0.35$, $\mu = 1.2$).

To sum up, the findings at the additional site proved to be consistent with the previous site when considering most aspects. The above Table 4 presents this comparison. This table shows that except for some findings closely relating with road layout, the rest could be generalized.

4. Discussion

This paper investigated pedestrians crossing behavior and safety at unmarked roadways with detailed analysis of several important behavioral patterns (e.g. running and looking patterns). The following sections first highlight some new findings about these behaviors and safety factors. Then limitations and possible applications of these findings to simulation modeling and educating pedestrians and drivers will be discussed.

4.1. New findings in this study

Unmarked roadway in China context yields new findings compared with current research or common sense. The following part highlights some of them.

4.1.1. Prefer active crossing rather than passively waiting for chance

Pedestrians at unmarked roadways have to depend upon themselves to choose whether to go or not. Therefore, instead of waiting passively, they try to cross actively by utilizing every possible chance. This leads to relatively aggressive crossing behaviors. For one thing, compared with pedestrians at the crosswalks, they preferred to check for vehicles during crossing rather than look before going. At crosswalks, pedestrians looked left and right to check the situation. If it were safe to go, they would cross without worrying too much about threatening vehicles. Hassan et al. (2005) found that pedestrians at signalized crosswalks spent 49% of the time looking left and right when they were waiting at the curb. However, they only spent less than 13% of the time doing that during crossing. This is contrary to the results obtained at the unmarked roadway, where no facility can distribute the shared space. Many pedestrians (65.7%) did not look at vehicles before crossing. Instead, they all looked at the traffic for a duration that nearly occupied 70% of their entire crossing time (see Fig. 7). For another, pedestrians have a similar short waiting time whether at the curb, at the median or in roadway. For those who waited, their waiting time followed an exponential distribution (see Fig. 3). This suggests that most pedestrians have relatively short waiting times (around 3 s) and only very few pedestrians have long waiting times (around 25 s). The behavior of looking while walking and the short waiting time that usually came with the act was aggressive. Pedestrians behaved in this way to gain access to the road forcefully. This could help to reduce their delay, but would also put themselves at risk.

4.1.2. Interaction with vehicles by running, stepping backwards or stopping

Unmarked roadways lead to more obvious interactions between vehicles and pedestrians than other crossing facilities. This part focuses on interactive behaviors on the pedestrians' side.

Due to complex situations at the unmarked roadway, pedestrians are not sure whether they could cross successfully or not. Therefore, they tentatively step slightly and monitor the area, paying attention to any unexpected changes in vehicles. If it is possible to cross, then they will go quickly or run towards the destination, otherwise they will stop in place or step back.

Running is a common behavior at crosswalks (Yang et al., 2006; Rosenbloom et al., 2008). However, running at unmarked roadways is different from doing it at crosswalks. At crosswalks, pedestrians run to follow others or use the limited green-light time left to reach the other side, regardless of the lanes in the street. At the unmarked roadway, pedestrians usually start and end their running at the borderline of lanes, aiming to cross the nearest lane before the arrival of vehicles. Since every place except the borderlines is risky on the road, this preference may imply that pedestrians view each lane as an independent crossing task (suppose there are oncoming vehicles in every lane). It is possible that after finishing each lane, they evaluate whether their present crossing method needs adjustment or not. If not, they go on without changing their behavior. However, if they detect a problem or danger they try and cross in a new way (e.g. changing from walking to running).

Stepping backwards is a behavior rarely reported at other crossing facilities. In most crosswalks, pedestrians just need to wait for the green light and then walk at ease. Although we only observed 11.4% of the pedestrians stepping backwards, this behavior at unmarked roadways reflects pedestrians' nervousness and diffidence.

4.1.3. Prefer safe than short crossing style

Intuitively thinking, crossing in the shortest path may result in less exposure to the dangers of the road and traffic. Perhaps this is why there is a tip for pedestrians on many accident prevention websites (e.g. www.china122.com/changshi/2010012491.html). This advice reads, "Try to cross straight" or "avoid crooked path." In some simulation tools (e.g. PEDFLOW), the direction change of pedestrians is determined by the shortest distance principle (Kukla et al., 2001). Although in some modeling works, pedestrians do take curved paths (Sakuma et al., 2005), the motive is to avoid static obstacles on the assumed shortest path when pedestrians start to walk. However, in the context of unmarked roadway crossing, even with no constraints like green belts or there being no vehicles along the shortest path, pedestrians do not take that shortest path. Vehicles are not static obstacles. They approach the intersection with a certain speed and at a definite distance, and in a very short time, they can arrive and block the area around shortest path. Accordingly, crossing using the shortest style seems to be a shortsighted choice in this situation. Pedestrians do not adopt it as they can make predictions of vehicle positions based on their estimated speed and distance to avoid potential dangers. In contrast to this style, walking along the borderline of lanes to find better gaps is a more appropriate strategy to cross fairly safe and quickly. It makes one safer in two ways. First, although pedestrians have to traverse a longer distance, the borderline does not constitute to a hazardous exposure relative to the traffic distance. Second, pedestrians who go along the lane borders for a big gap may converge into a bigger group, making it more possible to cut through vehicle flow (Wu et al., 2004).

4.1.4. Lognormal distributed safety margin and its predictors

The safety margin (safetyMarigin in Table 2) follows log normal distribution ($\sigma = 0.30$, $\mu = 0.96$, $\gamma = -0.23$), which suggests that more pedestrians distributed along the side with smaller safety margins. Although the coding process did not include pedestrians with safety margins greater than 6 s, it is still worth noting that 7.9% of the sample had a safety margin less than 1.5 s. Accidents will happen if anything wrong occurs on either the pedestrian's side (e.g. fall down) or the driver's (unexpected acceleration) side. This implies a potentially large chance of traffic accidents at the unmarked roadway.

The regression showed that pedestrians who are middle aged, looks at vehicles more frequently before crossing, interacts with buses rather than cars, or is included in bigger groups, tend to have a larger safety margin. However, running pedestrians usually had smaller safety margins. Middle-aged pedestrians usually have good perceptive skills and a high walking speed, but they are more conservative than their younger counter parts, thus likely to improve their safety. While it is obvious that pedestrians in groups are safer because they are more detectable, and running pedestrians are more dangerous because they gave a limited time for the driver to react, it is strange that pedestrians who step backwards had larger margins of safety. A possible explanation is that pedestrians were actually stepping out to test the situation and make a trial. They would take a brief moment to assess if they could cross safely or not, and if their evaluation convinces a daring reaction, then they will cross. Otherwise, they would pull back the foot and wait where they stand. Schmidt & Farber (2009) found at a 10% chance that people relied on leg movements to recognize pedestrians crossing intentions. Therefore, this behavior may give cues about the nature of behaving with the intent to cross to make drivers more prepared, which potentially leads to more safety.

4.2. Other findings

Except for the new findings above, similar results were found with previous studies. First, pedestrians cross the road halfway differently. They tended to cross more quickly on the far side. Moreover, the pedestrians also ran more when crossing the first two lanes of the far side compared with crossing the closer side. At signalized crosswalks, Yagil (2000) found that pedestrians were impatient to end their waiting at the second half and Tiwari et al. (2007) found that pedestrians tended to have more unsafe crossings on the far side. This all suggests that pedestrians wish to finish the crossing quickly at the far side. It is possible that pedestrians expect less danger at the end side, as the distance to cover is smaller. Secondly, it is found that common distractors of pedestrians include cell phones, eating, smoking, drinking, carrying something and talking with others. Some of these behaviors mentioned above has already been recorded by Bungum et al. (2005) in regards to signalized crosswalks. Due to the small sample in each category of distractors, the generalization of further findings is not proper. However, one point about grooming should be explained; the chance of this behavior happening became more frequent after the pedestrians started to cross the road. It would be somewhat strange to consider this a distractor as we assumed at first. Rechecking of the video discovered that pedestrians who engaged in this grooming behavior were mainly females. They seemed to groom their long hair just to get a better sight of the traffic.

4.3. Applications and generalization of the findings

The findings have several applications in improving pedestrian safety. First, it provides important information for further pedestrian modeling projects, which can be implemented in virtual reality to better train drivers and pedestrians. For example, it is found that pedestrians changed directions for a safer path because they had the ability to make predictions, rather than just perform in a dangerous and assumed way (e.g. shortest path). We also observed some distractors during crossing that might affect pedestrian (e.g. talk, use phone) judgments of situations. These dual tasks can be modeled similarly to the modeling of driver workload (Wu and Liu, 2007). In addition, the distributions of pedestrians' waiting and looking conduct can be used to model pedestrian behavior and set parameters in simulations.

Second, it can provide guidelines for the education of drivers and pedestrians as well as for urban design. For drivers, they may need specific training regarding the response to pedestrians at unmarked roadway locations. Findings in the current study can be used in the education and training of drivers so that they can know and expect the behavioral patterns of pedestrians at the unmarked roadway. For example, as pedestrians usually begin to run at the borderline between lanes, drivers should make conservative predictions of a pedestrian speed at those points in case of sudden running. Similarly, pedestrians like to walk faster on the far side, so drivers should be more careful (e.g. slow down) with respects to that case. For pedestrians, this study does not encourage them to cross illegally at any unmarked roadway. However, if they find themselves already crossing, they should take care and look for approaching vehicles more often at the curb, rather than performing this important task in the roadway. In our observation, 65.7% did not behave like this. They preferred to look while crossing, which was much riskier. Moreover, running is very dangerous, so they should walk quickly rather than run across the road. If they can send some signals to the drivers about their intent to cross (e.g. step out one foot), their safety can also be improved. Third, more attention should be paid to teenagers and elderly pedestrians. They are found to be less safe than middle-aged pedestrians. Therefore, it is recommended to implement special materials (e.g. reflect light well), perhaps to the canes of elderly pedestrians and the bags of teenagers in order to make them easier to detect by drivers.

These applications can possibly be generalized to other developing countries sharing many characteristics with China. Many developing countries have a large population and low car ownership (e.g. India) similar to China's current state. Since the road facilities are not well built (Tiwari et al., 2007) and the traffic regulations are not well obeyed (Ibrahim et al., 2005), many pedestrians cross roads at unmarked roadways. This situation, coupled with the shared use mechanism of the roadway (Tiwari et al., 2007) and the low yielding rate from drivers (Ibrahim et al., 2005), leads to high accident rates at unmarked roadways. These common characteristics make it possible to apply our findings to other similar contexts.

4.4. Limitations and future studies

Although this study provides detailed analysis of pedestrian behaviors at unmarked roadways, it has several limitations that need further investigation. First, some pedestrians in the observational study were ignored due to visibility problems and complex situations (e.g. vehicles blocked the pedestrians and it is very hard to code them, very complex interaction among road users, pedestrians pushing bikes). These missed cases may have affected the proportion of certain categories of pedestrians. For coded pedestrians, only some explicit and visible factors on demography, context and behavior were considered. However, the internal and invisible psychological aspects may influence pedestrians' safety a substantial amount. For instance, pedestrians with better judgment are likely to be safer. Moreover, since it is illegal to cross at unmarked roadways, different levels of law obedience may result in different behaviors. Neglecting influential factors can lead to low R^2 in the regression model. Second, some of pedestrians' attributes were not measured accurately. When crossing, they changed speeds very frequently and sporadically, but we can only measure the average speed based on the distance and time. Additionally, since it is extremely hard to measure the eye movements of pedestrians in these natural settings, we assumed that when pedestrians made head movements to the left and right, they were checking the vehicles. However, it is possible that they were actually looking at something completely unrelated. Also, because of the limited scope of the camera, we are unsure about how long they looked at vehicles before finally arriving at the curb. Finally, this is mainly a descriptive study on pedestrians crossing behaviors. Modeling and simulation of crossing processes based on these behaviors will be for future work and experiments to understand. Hopefully, later generations will discover new variables and measurement methods to accurately predict pedestrian behavior at unmarked roadways.

5. Conclusion

Pedestrians' crossing behaviors at unmarked roadways in China were addressed by field observation. The results showed that 65.7% of the pedestrians did not look at vehicles after arriving at the curb. Those who inspected for vehicles had a duration of looking that followed an exponential distribution. Pedestrians preferred crossing actively in tentative ways rather than waiting passively. The waiting time at the curb, at the median, and in the roadway all followed exponential distributions. During crossing, all pedestrians looked at the vehicles. When interacting with these vehicles, 31.9% of them ran and 11.4% stepped backwards. Running pedestrians usually began to run at the borderline rather than within lanes. Pedestrians preferred safe to short paths and they crossed the second half of the road with significantly higher speed. In terms of safety, pedestrians who were middle aged and a part of a bigger group were usually safer. Lastly, pedestrians who looked at vehicles more often before crossing or interacting with vehicles were safer while those who decided to run put themselves in peril. This discovery holds truer with buses more so than cars. These findings have potential applications in building pedestrian models and educating both drivers and pedestrians alike.

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References

Airault, V., Espié, S., 2005. Behavior model of the pedestrian interaction with road traffic In: Proceedings of the European Transportation Conference, Retrieved from http://www.etcproceedings.org/paper/download/185.

Brewer, M.A., Fitzpatrick, K., Whitacre, J.A., Lord, D., 2006. Exploration of pedestrian gap acceptance behavior at selected locations. Journal of the Transportation Research Board, 132–140.

Bungum, T.J., Day, C., Henry, L.J., 2005. The association of distraction and caution displayed by pedestrians at a lighted crosswalk. Journal of Community Health 30 (4), 269–279.

Cavallo, V., Lobjois, R., Dommes, A., Vienne, F., 2009. Elderly pedestrians' visual timing strategies in a simulated street-crossing situation. In: Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design Montana , USA.

Chu, X., Baltes, M.R., 2001. Pedestrian mid-block crossing difficulty. Technical Report, Retrieved from http://www.nctr.usf.edu, 1–79.

CRTASR, 2005. China Road Traffic Accidents Statistics Report of 2004. Traffic Administration Bureau of China State Security Ministry, Beijing, China.

Hassan, S.E., Geruschat, D.R., Turano, K.A., 2005. Head movements while crossing streets: effect of vision iimpairment. Optometry and Vision Science 82 (1), 18–26.

Hatfield, J., Murphy, S., 2007. The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. Accident Analysis & Prevention 39, 197–205.

Ibrahim, N.I., Karim, M.R., Kidwai, F.A., 2005. Motorists and pedestrian interaction at unsignalized pedestrian crossing. Proceedings of the Eastern Asia Society for Transportation Studies, 120–125.

Kukla, R., Kerridge, J., Willis, A., Hine, J., 2001. PEDFLOW: development of an autonomous agent model of pedestrian flow. Transportation Research Board, 11–17.

Li, Q., Wang, Z., Yang, J., Wang, J., 2005. Pedestrian delay estimation at signalized intersections in developing cities. Transportation Research Part A 39, 61–73.

Liu, X., Liu, X., Wang, Z., 2009. Effect of driver visual characteristics on road traffic safety. Tractor & Farm Transporter 36 (3), 59–60 (in Chinese).

Lobjois, R., Cavallo, V., 2009. The effects of aging on street-crossing behavior: from estimation to actual crossing. Accident Analysis & Prevention 41, 259–267.

Hamed, M., 2001. Analysis of pedestrians' behavior at pedestrian crossings. Safety Science 38, 63–72.

Mitman, Felig, M., Ragland, R, D., Zegeer, V, C., 2008. The marked crosswalk dilemma: uncovering some missing links in a 35-year debate. UC Berkeley Traffic Safety Center. Retrieved from: http://escholarship.org/uc/item/13r7q036.

Murray, S.J., 2006. The effects of simulated cellular phone conversation on road-crossing safety. Doctor of Philosophy, University of Canterbury, Retrived from http://ir.canterbury.ac.nz/bitstream/10092/1398/1/thesis_fulltext.pdf.

Ragland, R, D., Mitman, Fehlig, M., 2007. Driver/pedestrian understanding and behavior at marked and unmarked crosswalks.UC Berkeley Traffic Safety Center. Retrieved from: http://escholarship.org/uc/item/1h52s226.

Rosenbloom, T., 2009. Crossing at a red light: behaviour of individuals and groups. Transportation Research Part F: Traffic Psychology and Behaviour 12 (5), 389–394.

Rosenbloom, T., Ben-Eliyahu, A., Nemrodov, D., 2008. Children's crossing behavior with an accompanying adult. Safety Science 46, 1248–1254.

Sakuma, T., Mukai, T., Kuriyama, S., 2005. Psychological model for animating crowded pedestrians. Computer Animation and Virtual Worlds 16, 343–351.

Schmidt, S., Farber, B., 2009. Pedestrians at the kerb—Recognising the action intentions of humans. Transportation Research Part F: Traffic Psychology and Behaviour 12 (4), 300–310.

Simpson, G., Johnston, L., Richardson, M., 2003. An investigation of road crossing in a virtual environment. Accident Analysis & Prevention 35, 787–796.

Tiwari, G., Bangdiwala, S., Saraswat, A., Gaurav, S., 2007. Survival analysis: pedestrian risk exposure at signalized intersections. Transportation Research Part F 10, 77–89.

Wang, S., Li, X., 1995. Study on relation of chanacteristics of driver's action and reaction with traffic accident. Journal of Xi'an Highway University 15 (4), 59–65 (in Chinese).

Wu, C., Liu, Y., 2007. Queuing network modeling of driver workload and performance. IEEE Transactions on Intelligent Transportation System 8 (3), 528–537.

Wu, J., Huang, L., Zhao, J., 2004. The behavior of cyclists and pedestrians at signalized interactions in Beijing. Journal of Transportation Systems Engineering and Information Technology 4 (2), 1–10.

Wu, W., Juan, Z., Hongfei, J., 2009. Drivers' behavioral decision-making at signalized intersection with countdown display unit. Systems Engineering-Theory & Practice 29 (7), 160–165 (in Chinese).

Yagil, D., 2000. Beliefs, motives and situational factors related to pedestrians' self-reported behavior at signal-controlled crossings. Transportation Research Part F 3, 1–13.

Yang, J., Deng, W., Wang, J., Li, Q., Wang, Z., 2006. Modeling pedestrians' road crossing behavior in traffic system micro-simulation in China. Transportation Research Part A 40, 280–290.

Zhou, R., Horrey, W.J., Yu, R., 2009. The effect of conformity tendency on pedestrians' road-crossing intentions in china: an application of the theory of planned behavior. Accident Analysis & Prevention 41 (3), 491–497.