Older Pedestrian Crossing Behaviors and Crash Risks in Mid-Block Signalized Crosswalks

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Abstract: This paper presents our study that was conducted to investigate the correlations between crashes involving older pedestrians in the crosswalk and pedestrian behavioral characteristics. The start-up delay of road crossing, the number of head turns during cross walking, and the estimate of distance about approaching vehicles to the crosswalk were characterized by age groups. We found that there would be a close correlation between road crossing behaviors and crash risks involving older pedestrians: Older pedestrians have a shorter start-up delay in the crosswalk, older pedestrians would turn their head less frequently during the cross walking in comparison with younger pedestrians, and older pedestrians provide unreliable estimates about the distance of vehicles approaching to the crosswalk. This paper should be informative because little research had been conducted in South Korea to understand the crossing behaviors of older pedestrians in the mid-block crosswalk.

Keywords: Older Pedestrian, Crash Risk, Start-up Delay, Head Turn, Estimates about Distance of Approaching Vehicle, Mid-Block Crosswalk.

1. INTRODUCTION

World population is ageing (UN, 2016; MOI, 2015) and this trend in South Korea is remarkable as its percentage of ageing population who are 65 years old or more has been increasing substantially from 3.1% in the year 1970 to 12.2% in 2013 (MOI, 2015). Without dramatic change, this trend will stay and researchers expect that ageing population will occupy more than 40% of the total South Korean population (KOROAD, 2015; MOI, 2015). There are many problems associated with the ageing society (Bloom *et al*., 2011; Salvi *et al*, 2007; Christensen *et al*., 2009), and the loss of lives due to vehicle crashes is the most imminent problem (OECD, 2001; IRTAD, 2016; KOROAD, 2015). In particular, South Korea sees an exceptionally high number of fatal crashes involving older people (IRTAD, 2016; KOROAD, 2015, Lee and Kim, 2011; Lee *et al*., 2012). For example, a total number of fatal crashes involving older people in the year 2014 was 1,815, which occupies 38.1% of all road user fatalities (IRTAD, 2016; KOROAD, 2015).

The problem of older people crashes in South Korean can be highlighted by comparing the rate of older pedestrian fatalities per 100,000 people with those from other nations. In Figure 1, it is clearly seen that South Korea has the highest rate of older pedestrian fatalities in the OECD (Organization for Economic Cooperation and Development) nations (IRTAD, 2016). And it is worth noting that the second highest rate is only about 11 fatalities per 100,000 people and the average value for the OECD (Organization for Economic Cooperation and Development) nations is 3.2.

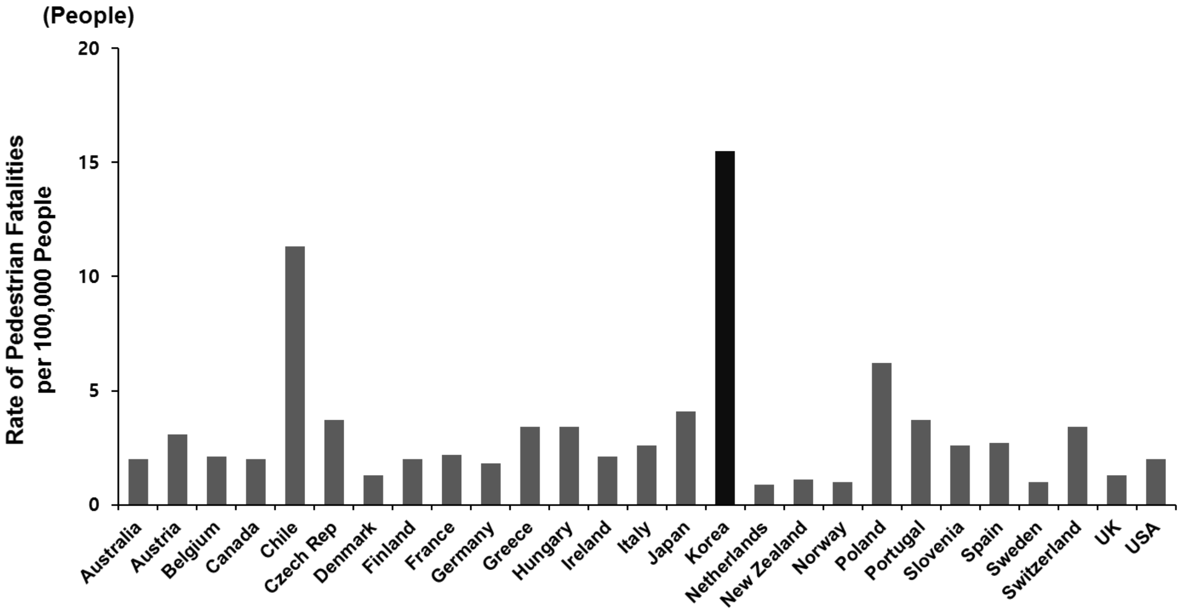

Figure 1. Fatalities of Older Pedestrians by OECD Nation, 2014

To cope with this problem of too many older pedestrian fatalities in South Korea, it is required to find major factors causing the crashes. We thus conducted literature review and found following general characteristics. First, vehicle crashes involving older pedestrians while they walk in the crosswalk was the most frequent crash type. In current literature, it is addressed that this case occupies a 37.6% of the total 29,969 older pedestrian crashes occurred in the year of 2012 to 2014 (KOROAD, 2015). Therefore, it is required to investigate what is happening in the crosswalk when an older pedestrian engaging in crossing activity. For instance, how promptly does he/ she react to the pedestrian signal in order to initiate cross walking? Does he/ she occasionally turn the head to look out traffic movement? Or, is his/ her estimate of the distance to approaching vehicles to the crosswalk reliable?

Second, older pedestrians are prone to crashes in the mid-block street section, although this finding also applies to the younger pedestrian case. Table 1 clearly shows that among South Korean pedestrian crashes totaling up to 12,281 for three years (from 2012 to 2014), mid-block street sections bear a more portion than intersections. Hence, the mid-block street section will be the area of investigation when the issue of crashes involving older pedestrians is discussed.

Table 1. Location of Pedestrian Crashes and Street Area (source: KOROAD, 2015)

	Mid-block			Intersection			Others	Sum
	Entrance of Crosswalk	Exit of Crosswalk	Unknown	Entrance of Crosswalk	Exit of Crosswalk	Unknown		
Older Pedestrians (number)	2,202 (19.5%)	1,791 (15.9%)	2,866 (25.4%)	1,156 (9.5%)	1,074 (10.2%)	1,996 (17.7%)	196 (1.7%)	11,281 (100.0%)
Younger Pedestrians (number)	7,432 (16.9%)	8,154 (18.5%)	11,807 (26.9%)	4,003 (9.1%)	4,008 (9.1%)	7,851 (17.9%)	707 (1.6%)	43,962 (100.0%)
All Ages (number)	9,223 (16.7%)	10,356 (18.7%)	14,673 (26.6%)	5,077 (9.2%)	5,164 (9.3%)	9,847 (17.8%)	903 (1.6%)	55,243 (100.0%)

Third, although many studies had been conducted to understand the gap acceptance, speed, visual search, vision and perception, cognitive impairment, and distraction of older drivers at intersections (Oxley et al., 1996; Oxley et al., 2004; Oxley et al., 2005; Wilton et al., 2007, Fildes, 1994), limited research had been conducted in South Korea to understand the crossing behaviors of older *pedestrians* (italic used intentionally by the author) and their associated effects to crash risks.
Nevertheless, the reason why so many older pedestrian crashes are occurring in South Korea can never be explained with these general characteristics only. The role of pedestrian walking behaviors within streets in the causation of older pedestrian crashes needs to be investigated. This paper is intended to lay out the main reason of South Korea's older pedestrian crashes. For this purpose, we believed that pedestrian cross walking behaviors needed to be statistically compared with those of younger pedestrians. We also believed that the crosswalk area should be first targeted because it involves the largest portion of South Korean pedestrian fatalities. Our result then can serve as the standard guidance to both those who are unfamiliar with older pedestrian crash study and those who may want to develop effective counter measures for older pedestrian crashes.

2. METHODOLOGY

2.1 Road and Crash Data

From 2012 to 2014, there were a total of 10,835 crosswalk older pedestrian crashes in South Korea, and Seoul city suffered from 2,119 crosswalk crashes, which was the highest number among major cities. Therefore, we selected Seoul as the case study area and decided to use 30 sites with the highest older pedestrian crosswalk crashes. Table 2 is the brief summary of these sites. It also provides the numbers of older and younger pedestrian crosswalk crashes for a three-year period (years 2012 to 2014). In detail, there were 139 and 284 crash occurrences for older and younger pedestrians, respectively.

Table 2. Road Inventory of Selected Sites

Site ID	Number of Lanes	Crosswalk Width (m)	Access Road	Guard Rail	Location of Bus Stop	*Sight Obstacles	Median Barrier	Number of Crashes for Three years	
								Older	Younger
1	6	6.3	Yes	Yes	Down stream	Yes	Yes	11	7
2	5	6.5	No	No	Up steam	Yes	Yes	11	37
3	10	12.1	Yes	No	Up steam	Yes	No	5	13
4	5	6.7	No	Yes	No	No	No	5	39
5	6	5.5	Yes	No	Down stream	Yes	Yes	4	15
6	4	7.2	Yes	No	No	Yes	No	4	14
7	6	7.8	No	No	Down stream	No	Yes	3	8
8	4	6.3	Yes	No	No	No	No	3	7
9	3	5.4	No	No	No	No	No	4	10
10	6	6.2	No	Yes	Down stream	Yes	Yes	6	4
11	6	6.7	No	No	Down stream	No	No	4	8
12	8	11.5	No	No	Down stream	No	No	3	4
13	8	11.7	No	Yes	No	No	Yes	4	4
14	8	12.2	No	No	Down stream	No	Yes	4	4
15	6	9.1	No	No	No	No	No	3	3
16	5	7.3	No	Yes	No	No	No	5	7
17	6	6.5	Yes	No	Down stream	Yes	Yes	5	5
18	6	6.0	Yes	No	Down stream	Yes	No	6	11
19	4	5.7	Yes	No	No	Yes	No	4	1
20	5	6.2	No	No	No	No	No	3	5
21	6	6.9	No	Yes	Down stream	No	Yes	3	5
22	6	7.5	Yes	No	Down stream	Yes	No	4	8
23	3	5.6	Yes	No	No	Yes	No	8	19
24	6	8.0	Yes	No	Down stream	No	Yes	5	8
25	4	6.1	Yes	No	Down stream	No	No	6	7
26	6	7.8	No	Yes	Down stream	No	Yes	4	6
27	4	6.2	No	No	Up steam	Yes	No	3	8
28	7	12.0	No	No	Up steam	Yes	No	3	6
29	10	12.3	No	No	Down stream	No	No	3	4
30	7	10.8	Yes	No	Down stream	Yes	No	3	7

* Sight Obstacles denote miscellaneous roadside facilities such as street vendors.

Our crash data as shown in Table 3 provides ages, the date and time, severity, and crude collision diagrams. Despite a relatively small sample size, if these crash information is combined with pedestrian behaviors in the cross walk, it will offer a good opportunity of understanding the reason why so many crashes involving older pedestrians occur in the cross walk. Thus, we established our own collision diagram as shown in Figure 2 to see if there would exist any particular crash patterns between crashes, pedestrian ages, and relative positions in the crosswalk. In this figure, the property damage only crash is ignored and crash severities are denoted with M for minor, S for severe, and F for fatal crashes. Meanwhile, total numbers of each crash severity are attached to these letters to inform how pedestrian crashes are scattered in the crosswalk. There were a total 423 crashes, but detailed information was available for 225 crashes only. We thus excluded the rest 198 crashes from further analyses.

Table 3. Summary of Pedestrian Crosswalk Crashes for Study Sites

	Older Pedestrian		Younger Pedestrian	
Number of Crashes	139		284	
Crash Severity				
PDO (property damage only)	8	(5.8%)	15	(5.3%)
Minor Injury	40	(28.8%)	115	(40.5%)
Severe Injury	83	(59.7%)	147	(51.8%)
Fatal	8	(5.8%)	7	(2.5%)

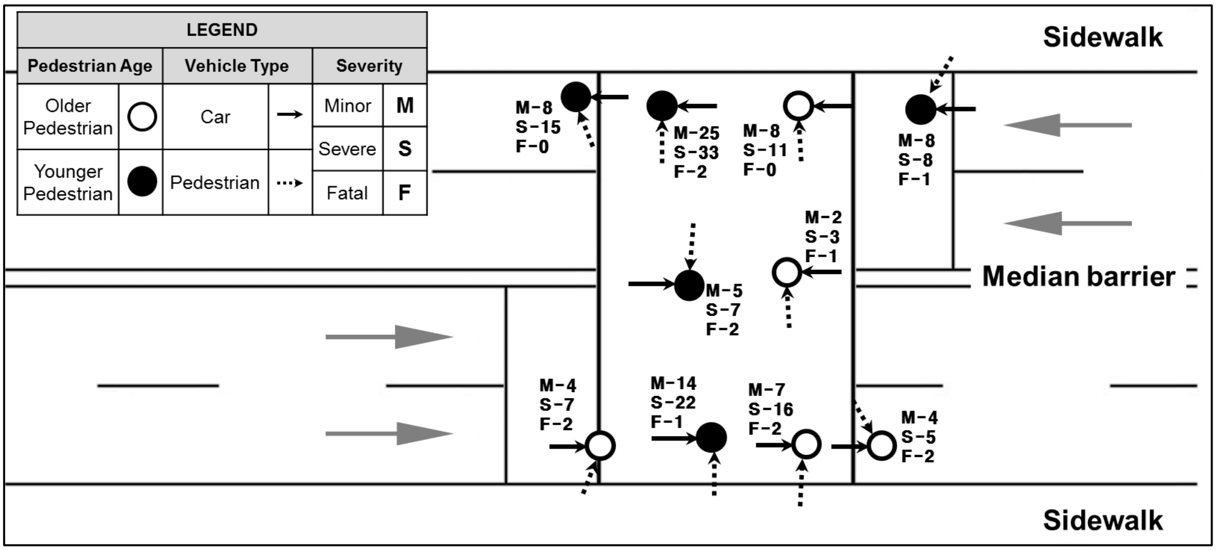

Figure 2. Crash Severity, Number of Crashes, and Relative Position in the Crosswalk by Age

2.2 Pedestrian Crossing Behaviors

To understand why crosswalk crashes involving older pedestrians are so many, we think that it is important to investigate any behavioral differences between older and younger pedestrians while they engage in cross walking. We thus conducted field studies for this purpose. The field study sites were the same sites as used in our previous crash study. The study period was from July 4 to July 15 in the year 2016, and we have used video cameras to capture pedestrian crossing in crosswalks. A total of 900 pedestrians were sampled for each age group. Leaders of each pedestrian platoon was always selected because they would be free from interruption from other pedestrians.

We then analyzed the video film in the laboratory with the following data refinement strategy. First, we assessed the start-up delay of a pedestrian, which is the time amount covering the start of the pedestrian signal to the moment when the pedestrian enters the crosswalk. This is a significant time value for investigating crosswalk crashes because numerous crosswalk crashes occur at the entering section of the crosswalk (Oxley, 1995; KOROAD, 2015). However, it usually falls in such a small value that we have decided to apply a mathematical equation as shown in Eqn. (1). Pedestrian crosswalk time for crossing one travel lane was determined by monitoring the video film. And total time spent in the crosswalk was also obtained from the video film by checking the elapsed time between the entering and exiting the crosswalk. These various time measurements were made right after the pedestrian signal turned to green. Figure 3 is a sample case showing how the start-up delay of a pedestrian crossing the crosswalk was analyzed.

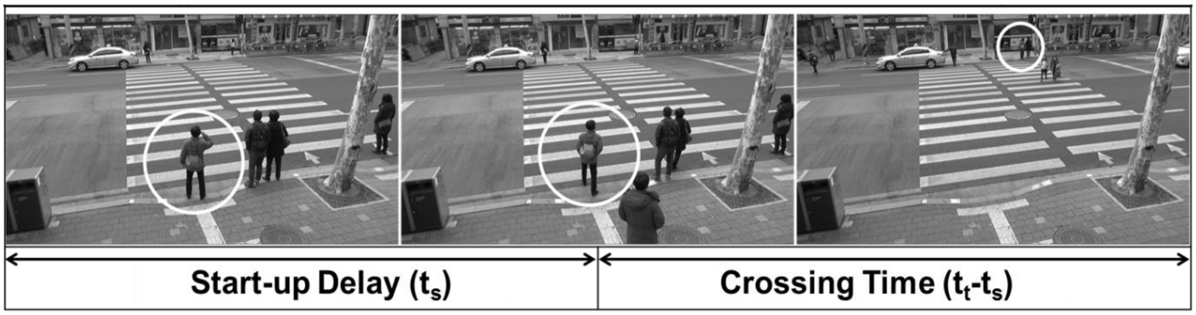

Figure 3. Field Measurement of the Start-up Delay of Pedestrian in Crosswalks

$$t_s = t_t - (n + m/w) * t_a \qquad (1)$$

where, t_s = start-up time for pedestrians in crosswalk
t_t = total time spent in the cross walk
n = number of lanes
m = median width
w = width of travel lane
t_a = pedestrian crosswalk time for crossing one travel lane

In the crosswalk, pedestrians are continually exposed to crashes with vehicles. However, a pedestrian who is attentive of surrounding traffic conditions may reduce crash risks (Corben, 1996; Lee et al., 2006, KOROAD, 2015). Therefore, it is very important to understand what kind of watchful behaviors they take and how these behaviors are correlated with crash risks. We have reviewed existing literature about pedestrian safety in the crosswalk (Oxley, 1996; WHO, 2013; Martin, 2006; Houten et al., 2001) and came to a hypothesis that a pedestrian who continually turns his/ her head to lookout any approaching vehicles in the crosswalk would have less crash risks. Hence, we analyzed the number of head turnings for each pedestrian in our video film. In this analysis, we counted one head turn when the pedestrian turns the head 60 degrees or more.

In the meantime, we wanted to complete our pedestrian behavior studies by investigating how reliably pedestrians estimate the distance (or time) of a vehicle approaching toward the crosswalk. This check is critical because older pedestrians will show the loss of vision and perception, cognitive impairment, etc., and their estimate of this distance (or time) may become unreliable (Corben, 1996; Lee et al., 2006; Stapline, 1990). Many older pedestrians were reported to be killed by cars in the crosswalk because of diminished mental capability (Oxley, 2005; Fildes, 1994). Therefore, we have conducted another field study to check the accuracy of distance estimations stated by older and younger pedestrians in the cross walk. The survey consisted of 15 randomly selected subjects for each age group. We then developed Eqn. (2) to check whether the estimated distances stated by the participating subjects were in error. Figure 5 is the configuration of pedestrian distance estimation for an approaching vehicle to the crosswalk. We anticipated that older pedestrians would provide unreliable estimations than younger pedestrians, contributing to more crash risks in the crosswalk.

$$t_v > t_a + t_s \qquad (2)$$
$$t_v > t_t - (1 + n + m/w) * t_a$$

where, t_v = vehicle running time to pedestrians
t_t = total time spent in the cross walk
n = number of lanes
m = median width
w = 1 vehicle travel lane width
t_a = pedestrian crosswalk time per vehicle travel lane
t_s = time obtained in Eqn. (1)

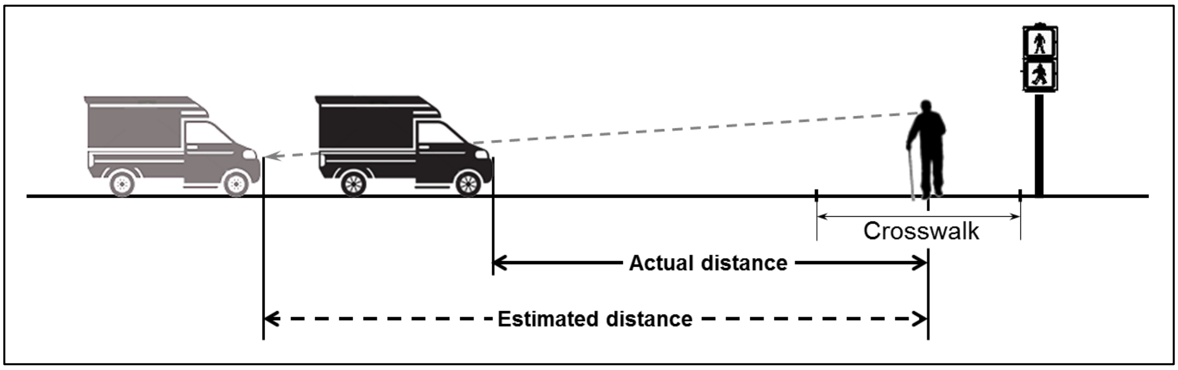

Figure 4. Field Survey of the Decision Error Rate at Crosswalk

3. RESULTS

Although it is widely believed that the start-up delay involving older pedestrians is greater than the one involving younger pedestrians (Olson, 1986; Park et al., 2008), our field study result provides as shown in Table 4 shows that older pedestrians have a shorter start-up delay in the crosswalk. Although younger pedestrians may be involved in distracted walking and this behavior will have some impacts to our result, this particular pedestrian behavior was not considered in this study.

Table 4. Pedestrian Start-up Delay in the Crosswalk by Age Groups

		Older Pedestrians	Younger Pedestrians
Sample Size (persons)		450	450
Start-up Delay	Average (s)	1.58	2.63
	Maximum (s)	2.85	3.75
	Minimum (s)	0.94	1.22
	Standard Deviation	0.48	0.67
	t-value	-6.885	
	p-value	0.000	

This contradicting result may be explained by one of the characteristics of older pedestrians who tend to initiate crossing the crosswalk without looking out both sides of street prior to the crossing. In fact, this opinion is upheld by investigating the scattering pattern of crashes involving older pedestrians in Figure 2. This figure reveals that, at the entering section of the crosswalk, the percentage of crashes involving older pedestrians per total older pedestrian crashes were 27.3%, while those of younger pedestrians were only 18.5%. Therefore, in order to improve the safety of older pedestrian in the crosswalk, it is recommended in traffic safety program to educate older people that they shall wait a while before entering into the crosswalk.

Our field study of pedestrian head turnings while they engage in cross walking was inspired by existing literature about older pedestrian behaviors in the road crossing (Fildes, 1994; Staplin, 1991; KOROAD, 2005). It is addressed (Fildes, 1994; Staplin, 1991; KOROAD, 2005) that although older people tend to feel difficult to turn their heads due to a stiff neck, more head turnings during the road crossing would be helpful to less crash risks. We also anticipated a similar outcome and found that actually older pedestrians would turn their head less frequently during the cross walking in comparison with younger pedestrians. Table 5 is the summary.

Table 5. Number of Head Turns by Age Groups

Category	Number of Head Turns per Crossing			
	Average	Standard Deviation	t-value	p-value
Older Pedestrians	3.15	0.573	-12.966	0.005
Younger Pedestrians	5.28	0.725		

Despite the result shown in Table 5 being significant in terms of different road crossing behaviors involving pedestrians by age group, this comparison bare little connection between crash risks and head turnings of pedestrians. Therefore, we decided to combine the results of Table 2 in the early part of this paper and Table 5. Figure 5 is the combined result. Interestingly, one more incredibly fascinating outcome has appeared, which clearly shows that older pedestrians in the crosswalk are likely to suffer a higher crash risk where they look out less frequently, i.e., fewer head turns, compared with younger pedestrians.

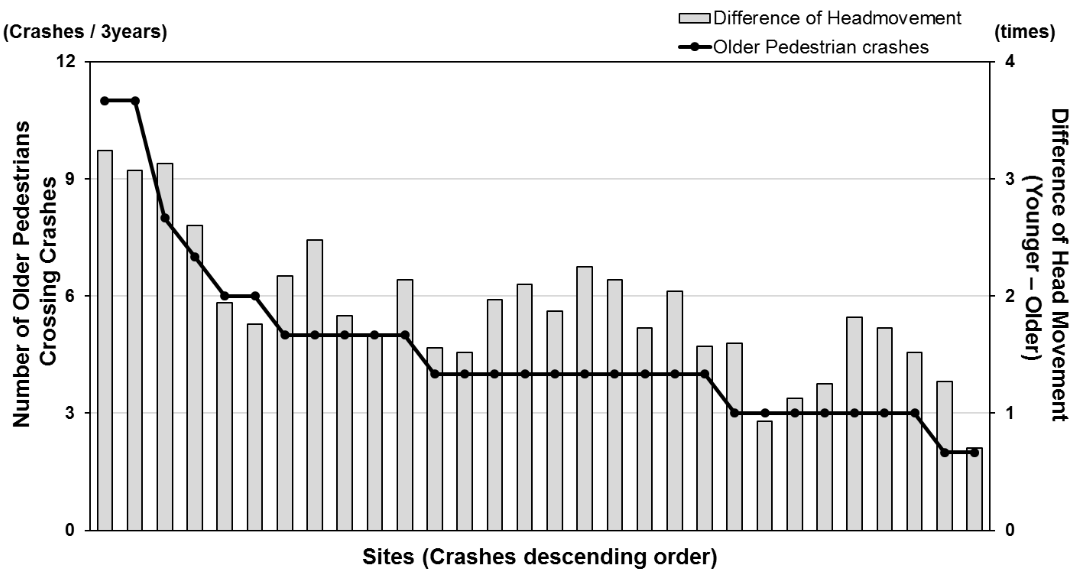

Figure 5. Crashes involving Older Pedestrians and Their Head Turn Behaviors

Finally, we acquired an investigation result that is distinguishable from the previous two results in the sense that this investigation dealt with the cognitive capability of pedestrians. We asked pedestrians in the cross walk to state their estimate of distance for a vehicle approaching to the cross walk. Obviously, older pedestrians are likely to provide less reliable answers and our result as shown in Table 6 proves this opinion true. First, compared with younger pedestrians, older pedestrians in the cross walk generally provide a higher standard deviation. Second, older pedestrians provide a greater average value when their estimated distance and actual distance of approaching vehicle were compared. Third, the number of pedestrians whose approaching vehicle were closer than they estimated were more than double those of younger pedestrians. In total, our findings are congruent with exiting literature about older pedestrian safety. Therefore, in order to assist older pedestrians in safer road crossing, the application of traffic safety devices such as better street lighting, the speed limit, the pedestrian actuated crossing signal, etc., should be greatly encouraged in the cross walk.

Table 6. Estimated Distance of Approaching Vehicles by Pedestrians, by Age Groups

		Older Pedestrians	Younger Pedestrians
Sample Size (person)		450	450
Pedestrians' Estimated Distance of Approaching Vehicles	Average (m)	46.4	48.6
	Maximum (m)	63.3	62.6
	Minimum (m)	38.9	35.2
	Standard Deviation	3.53	2.49
Estimated Distance – Actual Distance	Average (m)	3.7	2.6
	Maximum (m)	6.7	5.5
	Minimum (m)	0.5	0.7
	Standard Deviation	1.74	1.24
Pedestrians whose approaching vehicle were closer than they estimated	Average (Person)	2.6	1.2
	Maximum (Person)	6	4
	Minimum (Person)	0	0
	Standard Deviation	1.40	1.06
	t-value	4.375	
	p-value	0.042	
Average Vehicle Speed (km/h)		32.0	

4. DISCUSSION

Every year many older pedestrians are being killed in crosswalk crashes and this study investigates the causation between their road crossing behaviors and crash risks. Although many studies had been conducted to understand the road crossing behaviors of older pedestrians at intersections (Oxley et al., 1996; Oxley et al., 2004; Oxley et al., 2005; Wilton et al., 2007, Fildes, 1994), little research had been conducted at mid-block crosswalks despite that most fatal crashes involving older pedestrians occurred at this street section.

Our study findings are informative because there are local findings, which sometimes contradict but often constitute evidence of existing literature about older pedestrian safety. A good example of this contradiction is demonstrated by finding a 1.58 second start-up delay of older pedestrians in comparison with 2.63 seconds of younger pedestrians. This finding gives significance to crash risks involving older pedestrians in the crosswalk and we present its crash effects by providing Figure 3, which illustrates the crash severity, the number of crashes, and the relative position of crashes in the crosswalk by age groups. From now on, to cope with older pedestrian safety in the crosswalk effectively, South Korea needs to warn the public and in particular older people of the danger of the early start of road crossing in the cross walk.

Another interesting finding includes the effect of pedestrian head turns on crash risks in the crosswalk. We were of opinion that pedestrians inside the crosswalk should be extremely attentive of surrounding traffic conditions and the degree of pedestrian attentiveness could be captured by checking their head turns during the road crossing. Our finding proves that our opinion was right and Table 6 represents this evidence. Older pedestrians in the crosswalk are likely to suffer a higher crash fatality where they turn the head less frequently than younger pedestrians. Hence, older people should be advised through traffic safety programs that they need to continually look out approaching vehicles by turning their heads.

5. CONCLUSIONS

We found in this study that there is a close correlation between road crossing behaviors and crash risks involving older pedestrians. The followings are found.

- To determine whether older pedestrians should require longer cross walking time than younger pedestrians, we believed that the use of total cross walking time may not provide reliable answer, because many times older pedestrians involve serious crosswalk crashes while entering the crosswalk section. We thus require that the time of cross walking needs to be separated into the start-up time and the crosswalk time. It was then found that older pedestrians would have a shorter start-up time than younger pedestrians. Therefore, government agencies responsible for providing pedestrian safety devices and establishing human factor guidelines need to further investigate these issues.
- Older pedestrians would turn their head less frequently during the cross walking in comparison with younger pedestrians. Because of this characteristic, older pedestrians in the crosswalk may have suffered a higher crash risk. The role of the pedestrian head movement while cross walking in the causation of crashes should be further studied.
- Existing literature about older pedestrians (Oxley, 2005) understands that older pedestrians provide unreliable estimates about the distance of vehicles approaching to the crosswalk. Our results correspond to this study quite well, signifying that supplementary traffic control devices such as the speed limit should be installed in areas where older people make frequent cross walking.

Our study findings are limited to local conditions and international studies are recommended to increase our understanding of pedestrian crash risks in the crosswalk.

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