PEDESTRIAN ACCIDENTS WITH LEFT-TURNING TRAFFIC AT SIGNALIZED INTERSECTIONS: CHARACTERISTICS, HUMAN FACTORS AND UNCONSIDERED ISSUES

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INTRODUCTION

Accidents between vehicles and pedestrians represent an important safety issue for every country in the world. According to the National Safety Council, close to 20 percent of fatalities in road accidents in the United States are pedestrian fatalities (*1*). Of these fatalities, 26 percent occur in rural areas, whereas 74 percent occur in urban areas. Similarly, about 17 percent of non-fatal pedestrian accidents happen in rural areas and 83 percent in urban settings. It is not surprising that pedestrian accidents are especially problematic in urban areas since pedestrian activity is much higher there. Finally, it is estimated that 40 percent of pedestrian accidents occur at intersections.

This paper examines pedestrian accidents with left-turning traffic at signalized intersections. More specifically, this paper reviews the literature on pedestrians and drivers with an emphasis on human factors. We begin with a discussion on the characteristics of accidents between pedestrians and left-turning vehicles. Then, we describe various human factors aspects of drivers. These are related to the left-turning manoeuvre and the visual search for pedestrians. This is followed by a description of pedestrian characteristics, particularly in relation to intersections. Finally, we discuss accident dynamics and related issues, and proper future research.

PEDESTRIAN ACCIDENTS WITH LEFT-TURNING TRAFFIC

Approximately one out of five accidents at signalized intersections involve a turning vehicle hitting a pedestrian (*2*). The split between left-turning and right-turning accidents is about 60/40 (*2*, *3*). Furthermore, the proportion of accidents involving pedestrians and left-turning vehicles varies from 17 to 32 percent of all pedestrian accidents at the intersection (see Table 1). Thus, left-turning movements at signalized intersections represent a considerable safety problem to pedestrians.

Several authors have investigated pedestrian accidents involving left-turning vehicles. Among them, Habib (*4*) and Fruin (*5*) examined pedestrian accidents at signalized intersections on a one-way grid system in Manhattan, N.Y. They discovered that a left-turn movement was approximately four times more dangerous to pedestrians than a through movement. Almuina (*6*) examined accidents at one-way/one-way, one-way/two-way, and two-way/two-way intersections in Hamilton, Ontario. He demonstrated that with the exception of pedestrian accidents with straight-through vehicles, accidents involving left-turning vehicles had the highest proportion of accidents for all types of intersections. Using the same database, Quaye et al. (*7*) attempted to develop accident prediction models for pedestrian accidents involving left-turning vehicles for two types of intersections: T-intersections (3-leg) and X-intersections (cross-intersection or 4-leg). The models showed that T-intersections were generally more dangerous to pedestrians (for a pedestrian flow above 100 ped/hr). This result was also supported by Lord (*8*) who used the Traffic Conflict Technique to evaluate the intersections used in Quaye et al's study. Indeed, more conflicts occurred at sites characterized by a T-intersection.

Table 1. Pedestrian Accidents and Left-Turning Traffic
(*8*, adapted from *6*, p. 106)

Study:	Fruin (1973)	Habib (1980)	Zegeer et al. (1982)	Robertson & Carter (1984)	Zaidel & Hocherman (1984)	Almuina (1989)
Country	U.S.	U.S.	U.S.	U.S.	Israel	Canada
Proportion of left-turning accidents	31%	25%	22%	17%	13%	32%
Number of signalized intersections	32	45	1297	62*	520	306

* Only 54 intersections were signalized

DRIVER CHARACTERISTICS

Driving a vehicle involves many skills such as visual search, perception, and judgement. In order to minimize the risk of an accident, the driver has to continually process new information, react to the environmental demands and make proper decisions. In this section, the focus is on the drivers' understanding of different left-turning signals, drivers' response to pedestrians, and information processing.

Left-turning drivers can face three different signal alternatives at signalized intersections: 1) the permissive scheme, under which a driver has to let oncoming vehicles cross the intersection before undertaking the left-turning manoeuvre; 2) the protected scheme, under which a driver can turn without oncoming vehicles disturbing the manoeuvre; and, 3) the permissive/protected scheme, under which a driver can turn without oncoming vehicles disturbing the manoeuvre during a segment of the green phase (e.g., flashing green or green arrow). According to Hummer et al. (*9*), the understanding by motorists of these different signal alternatives varies. These authors conducted a survey of drivers on the different signal alternatives for left-turning manoeuvres in California. They found that the protected signals were best understood, followed by the permissive signals and the permissive/protected respectively.

The level of understanding can also be influenced by the consistency of traffic signals. As discussed by Alexander and Lunenfeld (*10*), drivers operate with a set of expectancies (e.g., freeway exits are located on the right hand side) and if these expectancies are violated there is an increased risk of an accident. Therefore, traffic control devices, including traffic signals, should be located and designed according to drivers expectations.

Traffic signals should be consistent in their type (e.g., horizontal or vertical heads), their location, and their interpretation (e.g., flashing green used as a protected left-turn). Unfortunately, many jurisdictions, particularly in rural areas, have traffic signals which are not consistent within the jurisdiction, let alone with neighbouring jurisdictions, such as in some Provinces in Canada for example.

A number of researchers have examined driver behaviour in the presence of pedestrians. Their studies usually involve the recording of vehicle speeds in the presence and absence of pedestrians. Katz et al. (*11*), for example, studied the situation in which drivers give way to crossing pedestrians in Israel. They found that a reduction in vehicular speed was noticeable at the crosswalk when pedestrians were present. These authors also discovered that a greater reduction in speed occurred when the number of pedestrians was greater than one. In contrast, Thompson et al. (*12*) studied driver behaviour in Nottingham, England but found no differences in speed when pedestrians were present. At the same time, they studied the position of the vehicle on the road (i.e., the distance from the curb) and found that drivers did not change their paths (i.e., moving further away from the curb) when pedestrians were present. Howarth (*13*) examined the interaction between drivers and child pedestrians also in Nottingham. He found that most drivers took avoiding actions within less than 20 meters from a child which was about to cross; this distance was less than the safe stopping distance in many instances.

The complexity of the primary driving task can greatly influence the peripheral detection of pedestrians. For instance, a driver who is approaching an intersection has to concentrate on the traffic lights (primary task) as well as to detect potential threats at and around the intersection (peripheral detection). Bartz (*14*) examined peripheral detection as influenced by the complexity of the primary task. Subjects had to verbally track a central task while attempting to detect small peripheral lights for different task complexity. Bartz found the peripheral detection deteriorates when the complexity of the task is either too low or too high. In the former case, a monotonous task reduces the alertness of an individual.

Driving a car implies simultaneous accomplishment of a variety of driving subtasks which constitute the drivers' workload. Harms (*15*) examined drivers' cognitive load when they were performing three manoeuvres at rural junctions in Sweden: straight, left-turn, and right-turn. Hancock et al. (*16*) did the same kind of study in California. Both found that the mental load was greatest for left-turning manoeuvres.

Visual search of drivers turning left at intersections is more frequent toward the right than the left. For example, Summala et al. (*17*) examined bicycle accidents and visual search at intersections in Finland. They found that drivers who are making left-turns made more head movements towards the right and closer to the intersection than right-turning drivers. Robinson et al. (*18*) also studied drivers visual search at intersections when they were turning onto a highway. They found that visual search time increased with the increase in traffic. They also observed that the last search before turning left on a highway was to the right (the fixations lasted for at least one second). Therefore, any changes to the left side of the driver would be unnoticed during this period.

After searching for potential threats, a driver must be able to perceive and identify these threats in order to take proper action to avoid a collision. At intersections, the detection of other road-users that are in motion can be very difficult. Indeed, the observer's self-motion in a stable environment produces an apparent visual motion or optic flow of the physical objects in that environment (*19*, *20*). Berthelon et al. (*21*) studied the perception of moving vehicles at intersections in France. They found that drivers travelling towards an intersection had difficulties detecting possible future collisions with vehicles whose path intersected their own. Stewart (*22*) attempted to explain child pedestrian accidents in England in terms of driver perceptual error. He discussed the effect of visual motion (optic flow) on the detection of pedestrians. This author demonstrated that drivers have difficulty estimating the possible path of a pedestrian in motion, which in turn may lead to a collision. Stewart supported this finding with statistics from accidents between pedestrians and vehicles.

Elderly drivers are more likely to be involved in intersection accidents than younger drivers (*23*). Garber and Srinivasan (*24*) compiled accident data from various cities located in Virginia. They found that the involvement ratios of older drivers to younger ones for right- and left-turn manoeuvres are significantly higher than for straight-through movements, the left-turning manoeuvres being the highest (see Figure 1). This finding is also supported by McKnight (*25*) who noted that traffic right-of-way violations for older drivers frequently involve left-turns. Cooper (*26*) surveyed elderly drivers in British Columbia and about 24 percent of the respondents (904) recognized that the turning manoeuvres gave them difficulties.

The higher involvement ratio for older drivers can be explained by various changes with age, including narrowing of their visual field, poorer contrast sensitivity, increased time required to change focus, slower eye movement, problems with depth perception, and slower decision making (*27*, *28*). Similarly, older drivers appear to have more difficulties in judging time-to-collision and acceptable gaps, especially when turning left at intersections (*29*).

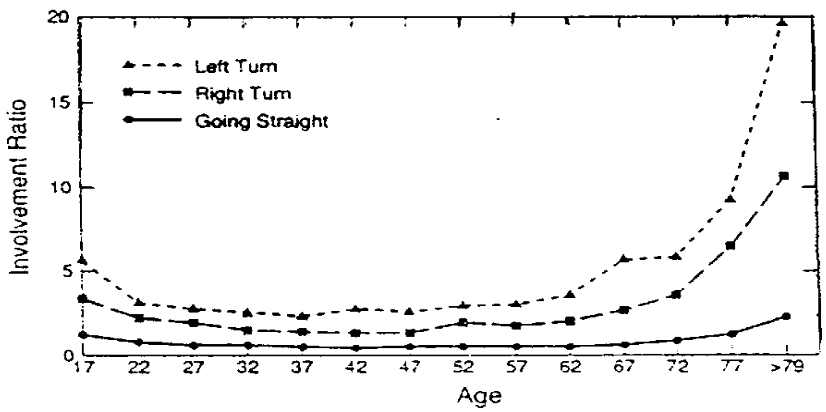


Figure 1. Involvement Ratio by Driving Manoeuvre (*24*, p. 15)

PEDESTRIAN CHARACTERISTICS

During a journey, the pedestrian needs to perform manoeuvres, detect obstacles, and make decisions. An error in these skills or physical limitations of the pedestrian may lead to serious injuries or death as the pedestrian interacts with vehicles. This section presents an overview of pedestrian characteristics including crossing time and visual search at intersections.

At signalized intersections, the green phase has to be long enough to permit pedestrians to cross safely. The current engineering standards establish the walking speed of pedestrians at 1.22 m/sec (4 ft/sec) for design purposes (*30*). However, many researchers consider this speed to be too fast for design purposes. For example, Fruin (*31*) examined the speed distribution of pedestrians in free-flow conditions in Port Authority and Penn Station, New York (see Figure 2). This author showed that nearly half of pedestrians walk below 1.22 m/sec. Bowman and Vecellio (*32*) examined pedestrian walking speeds at urban intersections located along arterial roads in the United States. They found that the average walking speeds were 1.35 m/sec for adults below 60 years of age and 1.03 m/sec for people above 60 years old. Knoblauch et al. (33) also did field studies of walking speeds at 16 crosswalks in the United States and found that the 15th-percentile walking speed of younger pedestrians (ages of 14 to 64) and older pedestrians (ages of 65 and above) were 1.25 m/sec and 0.97 m/sec respectively. In addition, they found that the walking speed is influenced by many factors such as weather conditions, type of street crossed, signal cycle lengths, medians, and crosswalk markings. None of these were, however, important enough to change the standard. Virkler and Guell (*34*) studied pedestrian crossing-time requirements at intersections in the United States. They found that the walking speed of pedestrians decreased as the number in the group got larger (especially for the people at the back of the group) and they proposed a new method to evaluate the minimum crossing time. These authors suggested a regression equation which takes into account the number of pedestrians in the platoon.

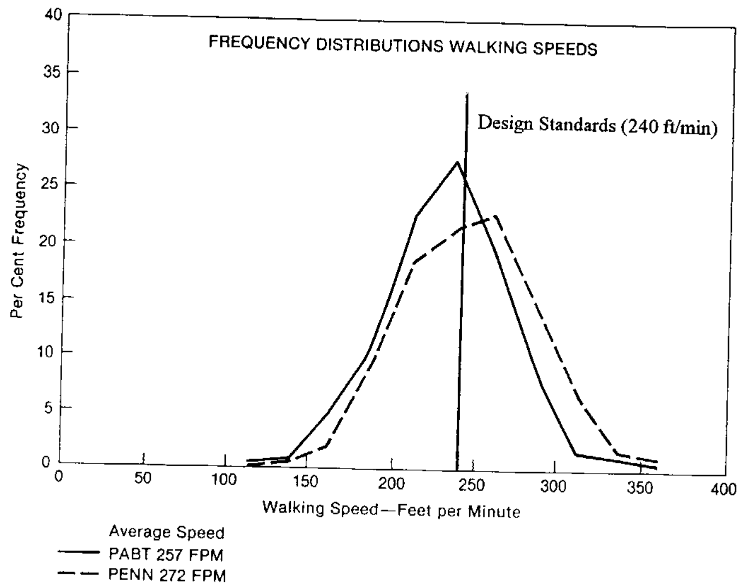


Figure 2. Pedestrian Walking Speeds in Free Flow (*31*, p. 40)

Signalized intersections can be provided with separate pedestrian signals (e.g. WALK and DON'T WALK). The use of pedestrian signals at an intersection is based on several criteria such as pedestrian and vehicle volumes, school crossings, and obstructed vision (*35*). The main purpose of pedestrian signalization is to improve safety by providing the pedestrian with better information as to when to start crossing. Unfortunately, pedestrian signalization fails to improve safety, as discussed by Robertson and Carter (*2*), Zegeer et al. (*3*), Khasnabis et al. (*36*), and Zaidel and Hocherman (*37*). Part of the ineffectiveness of pedestrian signalization can be attributed to the high violation rate (*38*) and part to the low comprehension rate (39). Indeed, it is estimated that only 39 percent of the population understand the meaning of the flashing hand.

Pedestrians also need to understand traffic signals for vehicles to know which phases are exclusive to vehicles and to know when to cross when no pedestrian signals are present. There may be an increased risk of collision if a pedestrian starts crossing during a protected left-turn phase because drivers may not expect a pedestrian then. Unfortunately, none of the studies reviewed examined this topic.

For pedestrians, visual search involves looking for vehicles before and during the crossing manoeuvre in order to avoid a possible collision. According to Shinar (*40*), pedestrian visual search and detection failures are the most common accident causal factors after the inappropriate crossing manoeuvre (see Table 2). Therefore, visual search and detection of vehicles by pedestrians are very important factors when it comes to crossing manoeuvres.

TABLE 2. Frequency of Primary Pedestrian Accident Causal Factors (*40*, p. 177)

FACTOR GROUP	NUMBER OF TIMES SELECTED	PERCENT OF FACTORS SELECTED	PERCENT OF ACCIDENTS SELECTED
Ped course	1206	30.6	55.9
Ped search and	1166	29.4	54.1
detection	238	6.0	11.0
Ped detection	158	4.0	7.3
Ped evaluation	17	0.4	0.8
Ped decision	19	0.5	0.9
Ped action			
Driver course	181	4.6	8.4
Driver search and	510	12.9	23.6
detection	292	7.4	13.5
Driver detection	82	2.1	3.8
Driver evaluation	75	1.9	3.5
Driver control-action	9	0.2	0.4
Driver and ped interaction			
Total	3953	100.0	

Visual search of pedestrians at signalized intersections differs according to age. Adult pedestrians make more head movements while approaching the curb than when they are at the curb, preparing to cross (*41*). According to Grayson (*41*), this suggests that adults make their assessment of the road situation before the curb is reached, often with the apparent aim to reduce delay at the curb. In another study, Jennings et al. (*42*) investigated pedestrian visual search at signalized intersections in Portland, Oregon where pedestrian signalization was present. The results of this study showed that pedestrians tended to search for potential threats during the DON'T WALK phase, but they did not search during the WALK phase (during the process of crossing).

The visual search of child pedestrians has been carefully observed by many authors. Unlike adult pedestrians, children make fewer head movements during the approach to the curb and more at the curb, which may imply that children monitor traffic at this location (*41*). In general, however, it has been found that children make more head movements than adults. Van der Molen (*43*) conducted an extensive review of the literature on children's exposure, accidents and behaviour in order to identify and implement educational strategies to improve children's safety. In his discussion, Van der Molen noted that children tended to increase their head movements when approaching the curb, while at the curb no significant differences were found. Van der Molen also reported that children make fewer head movements at a signalized pedestrian crossing than at other crossing situations since they appear to look more often at the signal. Preusser and Blomberg (*44*) examined children's behaviour as they were crossing a street after school. From field observations, it was found that only 12 to 23 percent of children in Los Angeles, Columbus and Milwaukee perform proper visual search.

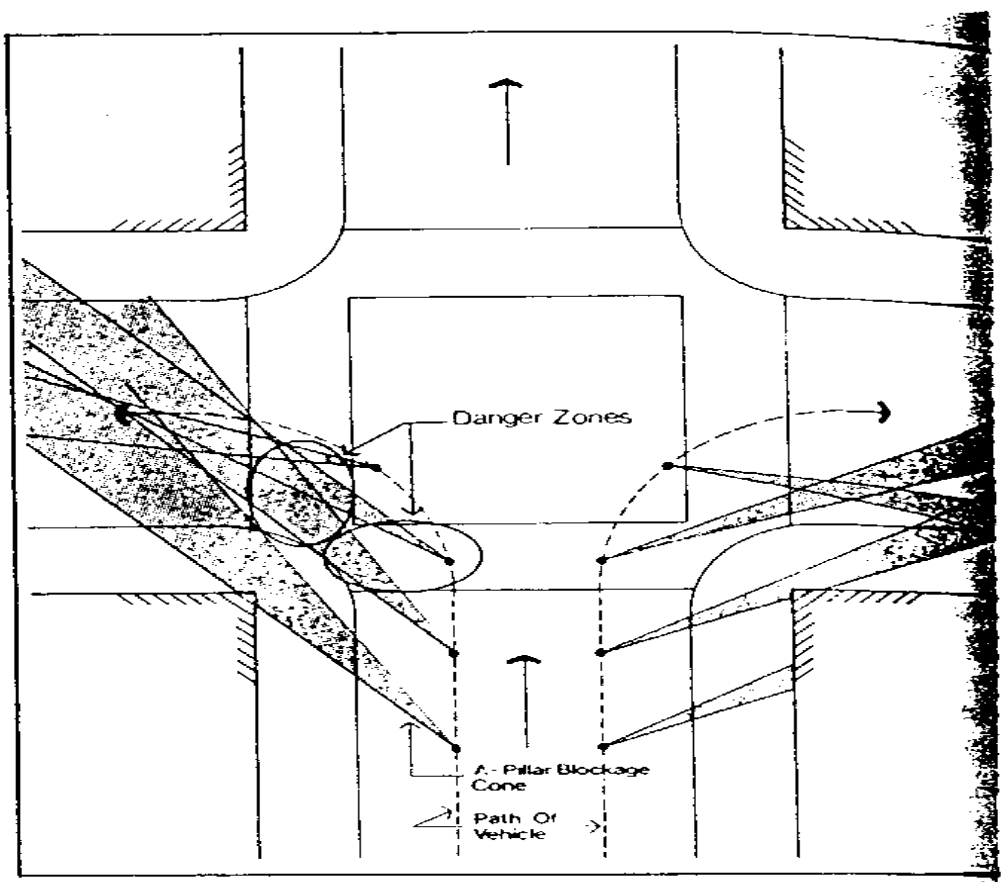
The visual search of older people is usually much less efficient than that of younger people. Dewar (*27*) identified, based on a FHWA report, several difficulties of older pedestrians such as less efficient visual search for vehicles and deterioration of the peripheral vision. Wilson and Grayson (*45*) supported these findings in their study of road crossing behaviour of senior pedestrians. They found that elderly pedestrians, like children, spend more time at the curb and make more head movements before and during the crossing manoeuvre. Elderly pedestrians also adopted different crossing strategies where they spend less time performing visual search while walking towards the curb. They tended to wait and scan before crossing.

Possible reasons have been put forward for the different visual search patterns of child and elderly pedestrians. Firth (*46*) suggested that the speed of eye movements, attention and memory may be of importance in producing differences between children and adults. Based on a literature review, Vinjé (*47*) reported that the visual field of children is limited by a restricted capacity to use information in the periphery of the visual field. As for the elderly, Firth suggested that elderly pedestrians may require more information than younger adults on which to base a decision. In addition, older people may not internalize as much information per observation (or head movement) as younger adults. Finally, they may need more time to differentiate relevant from irrelevant information.

DISCUSSION

Pedestrians at signalized intersections are at greater risk of being involved in an accident with a left-turning vehicle than a right-turning vehicle. Several suggestions have been put forward to explain the greater risk. Habib (*4*) and Dewar (*30*), for instance, noted that the driver's visibility impediment during a turning manoeuvre is greater for a left-turn (see Figure 3). As a result, a pedestrian has a greater chance of being lost in the A-pillar of the vehicle. Habib and Dewar also suggested that the visual search of drivers is focussed more to the right than to the left (e.g., see *48*). It can be assumed, according to these authors, that drivers at the intersection should spend more time scanning to their right and less to the left. However, one cannot suppose this since no studies specifically examined this issue at intersections. Dewar further stated that drivers have to constantly shift attention from the traffic lights to the crosswalk while approaching the intersection. As the driver gets closer, the angle between the crosswalk and the traffic lights increases which gives the driver less time to look at the crosswalk. According to Habib, a left-turning manoeuvre is more complicated than a right-turning manoeuvre. This fact is supported by Harms (*15*) and Hancock et al. (*16*) with their study of mental workload. As an attempt to explain this type of accident, Habib also claimed that drivers may consider the left-turning manoeuvre easier than a right-turning manoeuvre, when in fact it is not. There was, unfortunately, nothing in Habib's paper to support this statement.

Figure 3. Driver's Visibility Impediment During Intersection Manoeuvres



(*4*, p. 34)

The suggestions put forward above may be valid explanations of the causes of the accidents in question. However, some distinctions should be made between the different driver tasks that lead to intersection accidents. First, there should be a distinction between vehicles that turn left when the light is already green, and vehicles that are stopped at a red light and then turn left when the light turns green. In the former, the vehicle is usually moving as it approaches the intersection. A driver stopped at the intersection can look for pedestrians which are waiting to cross, and prepare for the proper turning manoeuvre. It is true, however, that not all drivers will look for pedestrians while waiting at the red signal. On the other hand, a driver who is travelling towards the intersection has to scan for pedestrians while moving. In this case, the driver may have less time to perform an efficient visual search.

The second distinction concerns the geometry of the intersection. There are three possible intersection geometries: one-way/one-way, one-way/two-way or two-way/two-way. Left-turning drivers behave differently depending upon the geometry. As described previously, Quaye et al. (*7*) discovered that, when no oncoming vehicles are present, left-turns are more dangerous to pedestrians than when oncoming vehicles are present (one-way/one-way and one-way/two-way). This finding appears to be unusual since when no oncoming vehicles are present, the driver performing the left-turning manoeuvre only has to keep track of the traffic lights and pedestrians on the crosswalk. On the other hand, in the presence of oncoming vehicles, the driver making the left-turning manoeuvre has to keep track of the traffic lights, the pedestrians, and oncoming vehicles simultaneously. In the latter, one would expect a greater work load and less visual search time available for pedestrians.

Lord (*8*) used the Traffic Conflict Technique to verify Quaye et al.'s (*7*) conclusions. Indeed, there were more conflict counts when no oncoming vehicles were present. Lord (49) noted that most of the conflict counts occurred during the first half of the green phase when both the driver and the pedestrian initiated their respective manoeuvres. Since the driving task is easier when no oncoming vehicles are present, the explanation for the greater conflict counts may be driver expectancy, in that during a left-turning manoeuvre, the driver looks less at the crosswalk area since he or she assumes pedestrians will not be crossing so soon. This author also noted that many conflicts occurred between the first, second or third vehicle in the queue and a pedestrian as opposed to late vehicles in the queue. Sometimes a conflict occurred with a vehicle closely following the first one. It can be assumed that the first vehicle obstructed the view of the driver in the following vehicle or that the driver glanced frequently at the first vehicle and less at the pedestrians on the crosswalk.

At two-way/two-way intersections, drivers making a left-turn usually have to let oncoming vehicles from the opposite approach pass before performing the manoeuvre. Lord (49) observed that while the driver was waiting for a gap long enough to turn, the majority of pedestrians usually had the time to cross the intersection. As a result, when the driver could finally turn left, there were very few pedestrians or no pedestrians at all in the crosswalk. Therefore, the risk to pedestrians may also be a function of the number of vehicles coming from the opposite approach. Another behaviour observed at two-way/two-way intersections involved drivers who stop in the middle of the intersection. Many drivers drove to the middle of the intersection to save time when turning left. Consequently, pedestrians were no longer located in the driver's blind area (A-pillar) but were then located to the left side of the vehicle. The visual search for pedestrians was still difficult since the angle between the crosswalk and the traffic lights was now greater.

As discussed previously, the detection of other road-users (pedestrians, cyclists, vehicles) may be more problematic than one might expect (*21*, *22*) because of the apparent visual motion of all physical objects in the intersection environment. However, since no research has specifically examined the relation between visual motion and pedestrians at intersections, it may be premature to conclude anything about the role of visual flow and the detection of pedestrians.

Drivers tend to detect pedestrians or at least modify their behaviour when the pedestrians are in a group (*11*, *12*). This fact was also noted by Lord (*49)*, where about three quarters of traffic conflicts involving pedestrians and left-turning vehicles involved only one pedestrian. Only one quarter of conflicts occurred when a group of pedestrians were crossing. These findings suggest that pedestrian safety is influenced by the number of pedestrians crossing at the same time. A bigger group of pedestrians may not be hidden by the visual impediment (A-pillar) of the driver turning left. In addition, drivers may be more cautious during the left-turning manoeuvre at intersections where a high number of pedestrians is present since these drivers expect pedestrians in their path.

So far, the discussion has focussed on the driver. In the literature, some authors assume that drivers bear a major part of the responsibility for an accident (e.g., *11*). However, a pedestrian-vehicle accident always involves two road-users; therefore, both road-users to a certain degree bear some responsibility. A pedestrian also needs to search and detect vehicles that are a potential threat. From the available research, pedestrians crossing at a signalized intersection attempt very little visual search for left-turning vehicles, especially for vehicles coming from behind (*50*, *51*, *52* as cited in *43*). Since about 40 percent of accidents involve a pedestrian walking towards a left-turning vehicle (*4*) (i.e., initial movement of cars and pedestrians are parallel and towards each other until the vehicle turns), one may inquire why these pedestrians failed to detect the left-turning vehicle when they need to move their head only a little to the left to search for the vehicle (as opposed to look behind to search for right turning vehicles). One also wonders if pedestrians over-estimate their safety at signalized intersections.

Pedestrians are at greater risk at night (*53*, *54*). A major part of this risk involves the low conspicuity of pedestrians (*55*, *56*, *57*), intoxicated pedestrians (*58*, *59*, *60*), and intoxicated drivers (*61*, *62*, *63*). A number of authors have examined night visibility of pedestrians by drivers and only a few studies have been conducted where street lighting was present (many intersections are provided with street lighting). However, no studies have specifically examined pedestrian visibility in the context of a left-turning manoeuvre at signalized intersections during nighttime.

FURTHER RESEARCH

Although there has been a great deal of research on pedestrians, very few studies were found which examined pedestrians interacting with turning vehicles at signalized intersections (*64*, *65*, *66*). These studies examined pedestrian behaviour and traffic conflicts between pedestrians and turning vehicles to evaluate the effect of interventions such as the installation of an auditory system or LED signal display. These studies did not assess the influence of intersection geometry, traffic control and traffic volume on pedestrian and driver behaviour. Future studies should examine the visual search of pedestrians by using cameras which record head movements, and if possible eye movements, as pedestrians walk towards the curb and as they reach the curb (before the crossing manoeuvre). A differentiation should be made for pedestrians waiting at the red light and those arriving at the curb during the WALK phase. The visual search of pedestrians should also be examined as a function of age and sex. Finally, studies should be conducted at intersections with various pedestrian and vehicular volumes, at signalized intersections without pedestrian signals, and at unsignalized intersections to examine if pedestrian behaviour (including visual search) changes in response to different traffic and traffic control conditions.

Very little research has been conducted on driver search for pedestrians at intersections. A method already employed by Summala et al. (*17*) and Robinson et al. (*18*) involves recording the visual search of drivers with a camera located at the intersections. The number of head movements as well as the duration of fixations should be recorded, if possible. As with pedestrians, it would be of interest to know the direction of the last head movement. Differences by age and sex should be examined. Visual search of drivers can also be recorded using an eye movement camera or a hidden video camera placed in a vehicle, as used by Rathmayer and Makinen (*68*). Subjects could be asked to drive a predetermined route in which several left-turns are performed at different intersection geometries. To avoid biased results, subjects should not be told that the study examines left-turning performances. Signs such as “Yield to Pedestrians” (*38*, *64*, *69*) could be evaluated to examine if the visual search for pedestrian is at all affected. Visual search during the red and green phases should be examined separately since there may be differences in the search for pedestrians. Intersections with different levels of pedestrian activity should be included. In particular, attention should be paid to the visual search of a driver following another when turning left. Finally, the same studies should also be carried out at night, with and without street lighting.

The theory of optic flow in the detection of pedestrians should be examined in the context of the left-turning manoeuvre. The methodology is already developed for other situations such as perception of vehicles at intersections (*20* and *21*). The subjects should be tested in the detection of pedestrians at intersections when they are moving in the same direction, and in the opposing direction of the subject’s vehicle (pedestrians facing or having their back to the vehicle turning left). This research would assist in understanding the visual cues needed to detect pedestrian in motion.

The results of the suggested research would enable the traffic engineering community to better understand the effects of signalized intersections on pedestrian safety. These results could be used to develop better criteria for the installation and location of new traffic lights. In addition, one should be able to evaluate pedestrian safety based on the geometry of the intersection, traffic volumes, and on vehicle and pedestrian characteristics. Similarly, the outcome of further studies would be very useful to target and evaluate specific interventions to improve pedestrian safety. This area has recently been examined (64, 65, 66, 69) but intervention which would take into consideration the visual search and detection of both drivers and pedestrians, and other characteristics, may provide a better improvement in pedestrian safety. In the end, the results would bring us a little closer as to why accidents between left-turning vehicles and pedestrians occur.

CONCLUSION

Accidents between pedestrians and vehicles represent an important safety problem. These accidents often lead to serious injuries and death since pedestrians are vulnerable when hit by a vehicle. In particular, a pedestrian is about four times more likely to be hit by a left-turning vehicle than by a right-turning vehicle at signalized intersections.

As shown in driver work load studies, the left-turning manoeuvre, at signalized intersections, is more demanding for drivers than right-turning or through manoeuvres, particularly for older drivers. Drivers appear to have problems with the visual search and detection of pedestrians. They perform more head movements to the right than to the left while turning left. They have difficulty perceiving other road-users that are moving in a stable environment. As the driving task difficulty increases, drivers have increasing trouble with the peripheral detection of targets. Senior drivers have reduced field of view and poorer depth perception; these decreases in ability specifically create hazardous situations for left-turning manoeuvres. The visual impediment created by the design of the vehicle (A-pillar) can also contribute to accidents between pedestrians and left-turning vehicles.

Several problems exist for pedestrians at intersections. At least half of pedestrians walk slower than 1.22 meters per second, the current engineering standard; many of these pedestrians are elderly people. Pedestrians often do not understand traffic signals and their violation rate is also relatively high. The visual search of pedestrians for vehicles at intersections varies according to age. Children and elderly pedestrians have more difficulty performing an efficient visual search. At all ages, pedestrians seldom perform proper visual search of drivers turning left at intersections.

Much research remains to be done to really understand accidents between left-turning vehicles and pedestrians at signalized intersections. The behaviour and information processing of drivers and pedestrians needs to be understood in relation to the design of the intersection, lighting conditions, type of signal phasing, and pedestrian and traffic flows.

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