

Unsafe at Any Speed?:

What the Literature Says about Low-Speed Modes

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UNSAFE AT ANY SPEED?:
WHAT THE LITERATURE SAYS ABOUT LOW-SPEED MODES

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ABSTRACT

The literature is reviewed on the safety of low-speed modes in the pedestrian environment, including walking, bicycling, skating, skateboarding, riding scooters, and operating wheelchairs, as part of a research and feasibility analysis of a pilot project that introduces shared Segway Human Transporters (HT), electric bikes, and bikes linked to a suburban Bay Area Rapid Transit (BART) District station and employment centers in Northern California. Advocates of the disabled, pedestrians, and the elderly have raised a number of concerns about the safety of the Segway HT in the pedestrian environment and its use has been banned in a few cities in California. The literature review provides insight into potential safety issues that may need to be addressed in the pilot project. A number of conclusions are made based on the results of this review. First, the risk of being injured while using a low-speed mode is relatively small. Second, most low-speed mode crashes do not involve collisions with other low-speed modes or motor vehicles (63% to 80%). Third, and not surprisingly, crash frequency in non-road and road environments appear to be related to the frequency with which the low-speed mode uses the environment. Fourth, the most common risk factors for low-speed mode crashes are surface conditions, user and motor vehicle driver error, obscured driver vision, and low-speed mode design characteristics.

Key words: safety, low-speed modes, transit access

INTRODUCTION

Access to transit stations is often a significant barrier to transit use in many urban regions. Parking during peak hours is often limited, and most people are only willing to walk about a quarter mile to transit stations (Cervero, 2001). While there are some effective feeder services (e.g., shuttles) that help extend the range of transit access, these systems are limited because of fixed routes and schedules. A number of strategies have recently been implemented to improve transit access, including bicycles, electric bicycles, carsharing, and personal neighborhood electric vehicles (Shaheen, 1999; Shaheen et al., 2000; Shaheen, 2001; Shaheen and Wright, 2001; Shaheen and Meyn, 2002).

Another mobility device that may improve access to transit stations is the Segway Human Transporter (HT). The Segway HT, brainchild of Dean Kamen, was unveiled in 2001 to accolades over its technological achievement and skepticism about its safety. The Segway HT was designed for the pedestrian environment. It is a self-balancing, two-wheeled electric device on which the operator stands upright and steers using weight distribution and a hand control. It weighs between 83 and 95 pounds and can attain a speed of 12.5 mph. A number of concerns about its safety in the pedestrian environment have been raised by disabled, pedestrian, and elderly advocates. They are particularly

concerned about the lack of space on sidewalks for the device and the potential for dangerous conflicts between Segway HT users and other pedestrians. Three cities in California have implemented Segway HT bans: San Francisco and La Mirada have implemented citywide sidewalk bans, and the Healdsburg has banned its use in four square blocks of downtown.

As part of a research and feasibility analysis of a pilot project¹ that introduces shared-use Segway HTs, electric bikes, and bikes linked to a suburban Bay Area Rapid Transit (BART) District station and employment centers in Northern California, researchers have reviewed the literature on the safety of low-speed modes that operate in pedestrian environments, including walking, bicycling, skating, skateboarding, riding scooters, and operating wheelchairs. The literature review provides insights into potential safety issues that may need to be addressed in the pilot project. For each low-speed mode, the authors describe regulations, operational characteristics, crash rates, and crash causes including locational and human factors. Conclusions are made about the relative risk of each mode and the most significant risk factors and the implications for the pilot project.

PEDESTRIANS

Background

In general, walking tends to be less attractive than driving for many “purposeful” trips because of relatively slower travel speeds and greater difficulty carrying packages (Goldsmith, 1993). Only 5.4% of all trips (Hu and Young, 1999), 2.68% of all commute trips (U.S. Census Bureau, 2003), and 8.5% of all commute trips five miles or less are made by foot (Pedestrian and Bicycle Information Center, 2003). In addition, it is well known that walk access to transit drops dramatically with distance from transit stations: approximately 85% of transit access trips are made by foot within 0.24 miles, 10% within 1 mile, and 2% within 2 miles (Federal Transit Administration, 1996; ctd Zegeer et al., 2002).

Characteristics

The physical abilities of pedestrians are described in a 1999 FHWA review on designing sidewalks (Axelson, 1999). The report states that “the concept of the ‘standard pedestrian’ is a myth; in reality, the travel speeds, endurance limits, physical strength, stature, and judgmental abilities of pedestrians vary tremendously” (Axelson, 1999, p.13). For example, the average walking speed for all pedestrians is 2.7 mph (U.S. Department of Transportation, 1988; ctd Axelson, 1999); for older pedestrians it is 1.9 mph (Staplin et al., 1998; ctd. Axelson, 1999). In addition, many pedestrians are able to change directions immediately, but older pedestrians or pedestrians burdened with objects may have limited maneuverability (Axelson, 1999).

Pedestrians tend to walk in the center of the sidewalk to allow space between themselves and the edge of the sidewalks (e.g., streets, telephone poles, and/or swinging

¹ This research is sponsored by the California Department of Transportation and evaluated by the University of California’s Partners for Advanced Transit and Highways

doors) (Axelson, 1999). This space, often referred to as a “shy distance,” reduces the effective sidewalk space available to pedestrian traffic (Axelson, 1999). For example, according to the Oregon Department of Transportation, pedestrians typically leave a distance of 24 inches on either side of the sidewalk to avoid buildings or obstructions (Oregon Department of Transportation, 1995; ctd Axelson, 1999). Thus, the effective space available to pedestrian traffic for a 10 feet sidewalk would be reduced to 6 feet (Axelson, 1999).

Regulation

Laws that govern pedestrian travel in California reflect concerns about potential conflicts between pedestrians and other vehicles (California Vehicle Code Sections, 21950, 21954-21956, 21960; ctd. American Automobile Association, 2003). These laws require that pedestrians (1) obey traffic rules and etiquette; (2) yield to oncoming vehicles if the vehicles pose a hazard to the pedestrian; (3) cross at marked crosswalks at an intersection; (4) walk on the left-hand edge of the road facing traffic if no sidewalk is available; and (5) not walk on certain roadways and freeways. These laws attempt to establish a clear separation between pedestrians and vehicles in order to avoid conflicts and maximize safety.

Crashes

Locational Factors

Several government studies evaluate pedestrian crash data and identify the frequency of conflict type (e.g., pedestrian only, pedestrian-bike, or pedestrian-motor vehicle) by location (e.g., sidewalk or roadway) (Hunter et al., 1996; Stutts et al., 1997; Shankar, 2003).

A 1997 FHWA study evaluated emergency room data from 1995 to 1996 on *pedestrian² only, pedestrian-bike, and pedestrian-motor vehicle crashes* from a number of hospitals in California, New York, and North Carolina (Stutts et al., 1997). Table 1 summarizes the pedestrian injury events by type and location from the study. It can be seen that more pedestrian injury events occurred in non-roadway locations (48.1%) than roadway locations (43.4%). The sidewalk was the most common location for pedestrian injury events (27.5% of total injury events). Pedestrian-only events were most frequent on sidewalks (41.6%) because of icy winter conditions in New York. Pedestrian-motor vehicle conflicts occurred most often on roadways (84.1%). The number of pedestrian-bicycle conflicts is small compared to pedestrian-motor vehicle and pedestrian only

² The study defines a pedestrian as any person engaging in an activity that does not involve a motorized or road vehicle (i.e., walking, running, playing, standing). This definition thus includes people with special equipment such as in-line skaters, rollerbladers, skateboarders, wheelchair users, people with strollers, and people walking bicycles. Out of the 1,345 cases where the pedestrian can be identified as having special equipment, only 15.2% of these cases involved people with special equipment. The study also includes conflicts that occur on any public or private grounds if a motor vehicle is involved, any location where there is vehicular traffic (i.e., parking lots, stores, businesses), and any “public transportation-related facilities not generally open to vehicular traffic” (i.e. sidewalks, multi-purpose trails) (Stutts et al., 1997).

crashes; however, most of the pedestrian-bicycle injury events occurred on the sidewalk (57.1%) (Stutts et al, 1997).

TABLE 1. Number of Pedestrian Injury Events by Type and Location

Injury Event Location	Ped-MV	Ped-Bike	Ped Only	Total
Roadway	439	8	188	635
Non-Roadway	57	12	635	704
Sidewalk	7	12	383	402
Driveway, Yard	15	0	53	68
Parking Lot	33	0	166	199
Off-road Trail, Park, etc	2	0	33	35
Other/Unknown	26	1	98	125
Total	522	21	921	1464

Source: Stutts, J.C. and W.W. Hunter (1997). "Injuries to Pedestrian and Bicyclists: An Analysis Based on Hospital Emergency Department Data."

A 1996 FHWA study analyzed 5,073 police reports from North Carolina, California, Florida, Maryland, Minnesota, and Utah in the years 1991 or 1992 on *pedestrian-motor vehicle crashes* (Hunter et al., 1996). Common locations of the crashes were roadways with no special features, intersections, and midblocks. The causes of intersection-related crashes typically included a turning vehicle, obstructed view of pedestrian, and driver violations. Most crashes occurred in a roadway-related environment (81.1%) rather than a non-roadway environment, such as sidewalks, walkways, and paths, (2.4%) because this study focused on pedestrian-motor vehicle crashes.

A 2003 NHTSA report, in which data from the Fatality Analysis Reporting System (FARS) from 1998 to 2001 on *pedestrian-motor vehicle crashes* were analyzed, found that out of 4,461 pedestrian fatalities in single vehicle crashes, 94.5% of the fatalities occurred in roadways and only 3.6% occurred on non-roadways (Shankar, 2003). Of the roadway fatalities, 21.4% were located at intersections and 78.6% were located outside of intersections (i.e., on crosswalks, roadways without crosswalks, parking lanes, bike paths, and outside traffic-ways). Of the fatalities located outside of the intersections, most of these (55.4%) were on roadways with no crosswalk available, where drivers likely could not anticipate a crossing pedestrian.

Human Factors

As described in the previous section, *pedestrian-motor vehicle crashes* appear to be most common at intersections and on roadways without crosswalks. The 1996 FHWA study indicates that pedestrians were most often at fault in pedestrian-motor vehicle crashes (43%) and that drivers were less often solely at fault (35%) (Hunter et al., 1996). Pedestrian negligence typically included "running into the road, failure to yield, alcohol impairment, stepping from between parked vehicles, and walking or running in the wrong direction (with traffic)" (Hunter et al., 1996, p.149).

It appears that younger individuals are more likely to be involved in pedestrian-motor vehicle crashes than older individuals. The 1996 FHWA report indicated that

29.8% of the pedestrians injured were less than 15 years old and that 29.7% of the pedestrians injured were between the ages of 25 and 44 (Hunter et al., 1996). In the 1997 FHWA study, it was found that 30.4% of injured pedestrians were less than 15 years old (Stutts et al., 1997). These trends may be explained by higher rates of walking among younger individuals and poorer judgment because of their relative inexperience. However, pedestrians over 45 are more likely to be injured by icy conditions on non-roadways (e.g., sidewalks) (Stutts et al., 1997).

BICYCLES

Background

Bicycling tends to be less attractive than driving and walking for most trips (U.S. Census Bureau, 2003; Hu and Young, 1999) because of relatively slower travel speeds, difficulty carrying packages, safety concerns, and/or adverse weather conditions (Goldsmith, 1993). In the 2000 U.S. Bureau of Transportation Census, only 0.44% of commuter trips were by bicycle while 2.68% were by foot and 87.5% were by car (2003). The results of the 1995 Nationwide Personal Transportation Survey indicated that most people bicycle for social or recreational purposes (60%), but some also bicycle for personal or family business (22%) and for their commute (8%) (Hu and Young, 1999).

Characteristics

Bicycle travel tends to have significantly greater operational requirements than pedestrian travel. Bicycles typically require a total 3.3 feet of operating width, which includes 30 inches of occupied space and 5 inches of free space on either side (American Association of State Highway and Transportation Officials, 1999). In California, sidewalks have a minimum width requirement of 4.9 feet (California Department of Transportation, 2001). If a bicyclist uses a sidewalk with a width of 4.9 feet, then only 1.6 feet of space would remain for other sidewalk users. Most bicyclists travel almost six times the speed of a typical pedestrian (15mph) (Allen et al., 1998, p. 30; U.S. Consumer Product Safety Commission, 2002a, p.2). Pedestrians can stop almost immediately, but bicycles traveling at 15 mph must take 15 feet to stop (U.S. Consumer Product Safety Commission, 2002a) or, if traveling at half that speed on dry concrete, 2.1 feet (Science Learning Network, 2003). The turning radius for a bicyclist, traveling at 15 mph with a lean angle of 15° is 56.3 feet and at half that speed with a lean angle of 15° 14.1 feet (American Association of State Highway and Transportation Officials, 1999). Pedestrians can turn in place. In sum, bicycles operate at faster speeds, need a greater distance to brake, and require more space to turn than pedestrians.

Regulation

Because of their operational characteristics, bicycles are typically defined as motor vehicles and thus must follow many of the same laws. For example, in California, “bicycle riders (cyclists) on public streets have the same rights and responsibilities as automobile drivers” (California Department of Motor Vehicles, 2000). More

specifically, bicyclists are required to use left and right turn lanes and ride in the same direction of traffic (California Department of Motor Vehicles, 2000). Riding on the sidewalks is discouraged (California Department of Motor Vehicles, 2000) and several localities have explicitly prohibited it (e.g., San Francisco Traffic Code; American Legal Publishing Corporation, 2002a, 2002b).

American Association of State Highway and Transportation Officials (AASHTO) guidelines also caution against riding on sidewalks: “sidewalks are typically designed for pedestrian speeds and maneuverability and are not safe for higher speed bicycle use” (AASHTO, 1999, p.58). AASHTO also mentions that motor vehicles do not expect higher speed bicyclists to enter crosswalks from sidewalks and that a bicyclist’s sight is often blocked by obstructions such as buildings or shrubs (American Association of State Highway and Transportation Officials, 1999).

Crashes

One 2002 study based on data from the National Electronic Injury Surveillance System (NEISS)³ and the National Sporting Goods Association (NSGA)⁴ estimated sports’ injury rates based on participation and found that bicycling has a higher injury rate (11.5 injuries out of 1,000 participants) than skateboarding (8.9 out of 1,000) and in-line skating (3.9 out of 1,000), but a lower injury rate compared to basketball (21.2 out of 1,000) or football (20.7 out of 1,000) over the course of one year (1998) (Kyle et al., 2002). Another study examined more recent data from the U.S. Consumer Product Safety Commission (CPSC) and the NSGA and found that, when injury rates are considered per 10,000 days of participation, bicycling has the second highest injury rate (2.05), behind skateboards (2.51), and followed by in-line skating (1.71), and scooters (1.03) (U.S. Consumer Product Safety Commission, 2002b).

Locational Factors

A number of studies evaluate bicycle crash data and identify frequency of conflict type (e.g., bicycle only, bicycle-bike, or bicycle-motor vehicle) by location (e.g., sidewalk or roadway) (Stutts et al., 1997; Aultman-Hall and Adams, 1998; Wachtel and Lewiston, 1994; Tinsworth et al., 1993; Hunter et al., 1996).

The 1997 FHWA report that evaluated emergency room data on *bicycle⁵-only*, *bicycle-pedestrian*, *bicycle-bicycle*, and *bicycle-motor vehicle* crashes found that bicycle crashes are most common on the roadway (58.3%) and less common in the non-roadway environment (26.4%) (Stutts et al., 1997). Table 2 summarizes the bicycle injury event type and location from the study. The author noted that these results can be explained by the fact that bicycles are most often relegated to the roadways. Moreover, most of the

³ Kyle et al. (2002) report that the NEISS provides an estimate of the number of consumer product-related injuries nationwide through a sample of injuries from a number of hospital emergency departments throughout the United States. This study used NEISS data from 1987 to 1998.

⁴ According to Kyle et al. (2002), the NSGA data were collected from 1987 to 1998 from a panel survey of 20,000 households.

⁵ The definition of bicyclist in this report is “any person riding or being carried on a bicycle or other two- or three-wheeled vehicle operated solely by pedals” which includes “bicycle, tricycle, big wheel, pedal scooter” (Stutts et al., 1997).

bicycle crashes on the road are bicycle-only events (53.4%) and fewer are bicycle-motor vehicle conflicts (43.1%). In the non-roadway environment, bicycle-only injury events were most frequent (84.7%), and the sidewalk was the most common location of the injury events. Compared to the total number of bicycle crashes and the bicycle-only crashes, conflicts on the sidewalk between bicycles and pedestrians and other bicycles were insignificant (Stutts et al., 1997).

TABLE 2. Number of Bicycle Injury Events by Type and Location

Injury Event Location	Bike-MV	Bike-Bike	Bike-Ped	Bike Only	Total
Roadway	280	15	8	347	650
Non-Roadway	23	10	12	249	294
Sidewalk	15	3	12	131	161
Driveway, Yard	0	1	0	25	26
Parking Lot	6	0	0	17	23
Off-road Trail, Park, etc	2	6	0	76	84
Other/Unknown	17	3	1	150	171
Total	320	28	21	746	1115

Source: Stutts, J.C. and W.W. Hunter (1997). "Injuries to Pedestrian and Bicyclists: An Analysis Based on Hospital Emergency Department Data."

One study of 2,963 *commuter bicyclists* in Ottawa and Toronto, Canada, also found that crash events occurred more frequently on roads than on sidewalks (Aultman-Hall and Adams, 1998). There were few sidewalk falls (9.9% of total falls in Ottawa and 9.3% in Toronto) and fewer sidewalk collisions (4.2% of total collisions in Ottawa and 7.0% in Toronto). The authors noted that many of the sidewalk events documented in this study were not reported to the police and thus would not have been found in police crash databases. Sidewalk bicyclists, however, report more near misses with other bicyclists than bicyclists on the roads. The study also found that bicyclists use sidewalks on major roads, to cross bridges, take shortcuts, and on high-volume roads (Aultman-Hall and Adams, 1998).

Another study analyzed police records of *bicycle crashes* (from 1985 to 1989) and *bicycle counts* in Palo Alto, California, and found that bicyclists riding on the sidewalk or a bicycle path ran a greater risk of injury at intersections⁶ than bicyclists riding on the road (2.4% of 2,005 roadway bicyclists injured whereas 4.2% of 971 sidewalk bicyclists injured) (Wachtel and Lewiston, 1994). Sidewalk bicycling incurred "greater risk than those on the roadway (on average 1.8 times greater), most likely because of blind conflicts at intersections" (p. 35). Bicycling against traffic on the sidewalk increased the risk of being injured (2.2% of 2,553 sidewalk bicyclists riding with traffic injured whereas 7.8% of 423 sidewalk bicyclists riding against traffic injured) (Wachtel and Lewiston, 1994). The authors also noted that "sidewalk bicycling appears to increase the incidence of wrong-way travel" (Wachtel and Lewiston, 1994, p. 35).

In another study, Consumer Product Safety Commission (CPSC) investigators conducted a phone investigation of *all bicycle-related injuries* in the NEISS from January through December 1991 (Tinsworth et al., 1993). The authors found that bicycle injuries

⁶ Wachtel et al. (1994) defined an intersection as "any point where turning or crossing movements are possible for the bicyclist or the motorist," which includes paths meeting a roadway or sidewalks or paths meeting driveways.

occurred most often on neighborhood streets (41% on neighborhood streets, 12% on sidewalks/playgrounds, and 28% at “other” locations). Most of the crashes resulted from uneven or slippery surface conditions (42%), excessive speeds (22%), and/or a collision with a moving or non-moving object (28%) (Tinsworth et al., 1993).

The 1996 FHWA report also reports on *bicycle-motor vehicle crashes* (3,000 cases). Common roadway locations for these crashes include intersections (50.4%) and driveways (19.1%) (Hunter et al., 1996). In both these locations, driver’s vision of bicyclists may be obscured. Most crashes occur on the roadways, particularly at crosswalks. Only 2.3% of all crashes are in non-roadway locations.

Human Factors

Several government studies address the human factors that contribute to bicycle crashes (Hunter et al., 1996; Clarke and Tracy, 1995; Stutts and Hunter, 1997).

The 1996 FHWA study reports that, for *bicyclist-motor vehicle crashes*, bicyclists were solely at fault 50% of the time and drivers were solely at fault 28% of the time (Hunter et al., 1996). Bicyclist errors leading to these crashes typically included a failure to yield (20.7%) and riding against traffic (14.9%) (Hunter et al., 1996).

A 1995 FHWA report, which cites a study of *bicycle crashes (all types)* in Winnipeg, Canada, also described the frequency of bicyclist errors leading to crashes: failure to yield (15.1%), riding on the sidewalk or in the crosswalk (14.3%), and disobeying stop sign/red light (11.1%) (Thom and Clayton, 1992; ctd. Clarke and Tracy, 1995).

Again, it appears that younger individuals are more likely to be involved in bicycle crashes than older individuals. The 1996 FHWA report found that 45.1% of *bicyclist-motor vehicle collisions* involved people less than fifteen years old and 23.1% of collisions involved twenty-five to forty-four year olds (Hunter et al., 1996). The 1997 FHWA report provided similar results: 45.1% of bicyclists involved in crashes were less than fifteen years old, and 23.0% were between the ages of twenty-five and forty-four (Stutts and Hunter, 1997). This study also reported that bicyclists less than fifteen years old dominated the non-roadway, bicycle-only events (60.6%) and those twenty-five to forty-four year olds dominated the bicycle-motor vehicle events for both roadway and non-roadway locations (32.9% for roadway and 40.9% for non-roadway) (Stutts and Hunter, 1997). Again, these age-related trends may be explained by higher participation rates among the identified age groups and poorer judgment of younger individuals because of their relative inexperience.

SKATES

Background

The popularity of skating has dramatically increased in recent years; the number of in-line skaters has grown from 3.1 million in 1989 to 29.1 million in 1997 (Osberg et al., 2000). In this section, in-line skating and roller skating are treated interchangeably unless otherwise noted. In-line skates are skates whose wheels are in one single line. Roller skates consist of four wheels, two in the front and two in the back.

One author conducted an on-line survey⁷ of frequency and purpose of skate travel (Osberg et al., 2000). Of the 339 people who participated in the survey, most responded that they skate to visit friends (39% responded “sometimes” and 26.9% responded “often”) or run errands (37.2% responded “sometimes” and 18.0% responded “often”). Fewer respondents indicated that they skate to work (15.8% responded “sometimes” and 8.1% responded “often”) (Osberg et al., 2000).

Characteristics

Several studies describe the operational characteristics of in-line skaters. In one study, observations⁸ and measurements of in-line skaters were taken at three separate locations (sidewalk, asphalt trail, and long asphalt road) in Florida with the assistance of video cameras (Birriel et al., 2001). The modal speed was approximately 10.5 mph and the highest speed was greater than 19.5 mph. Schieber et al. (1994), cited similar speed ranges, 10 to 17 mph. These speeds are almost four to eight times as fast as walking speeds. The modal sweep width, or lateral distance the skater occupies, was 4 feet and the largest sweep width was greater than 7 feet. The modal stopping width was 4 feet and the largest stopping width was 12 feet. The modal stopping distance was 20 feet and the longest stopping distance was 95 feet (Birriel et al., 2001).

Another study cited “Guidelines for Establishing In-Line Skate Trails in Parks and Recreational Areas,” which found that “experienced skaters commonly reach cruising speeds of 10 to 17 mph” (International In-Line Skating Association, 1992; ctd. Schieber et al., 1994).

Allingham and MacKay (1997, p. 13) in “In-Line Skating Review, Phase 2” report that a “‘skilled’ in-line skater traveling at a similar speed to a bicycle, can stop in the same or shorter distance.” The required lateral width was 14.9 feet, plus a maneuvering allowance of 1.3 feet on each side of the skater. Thus, the skater would require 7.5 feet of operating width. Skaters can achieve speeds of over 15.5 mph and “the differences in speeds between bicycles and other conveyances, including pedestrians, can result in a potential safety hazard on some facilities” (Allingham and MacKay, 1997, p. 15).

Regulation

Because of potential safety hazards posed by skating, some cities have imposed bans or regulations on skating (Osberg et al., 2000). Skate bans are usually found in congested areas; for example, the city of Pittsburgh prohibits roller skaters on the sidewalks in business districts (Osberg et al., 2000). Other areas, such as The Dalles, Oregon, regulate skaters as they do bicyclists (Osberg et al., 2000). Some areas consider skates to be recreational equipment; for example, regulations in Arlington, Virginia, state that “no persons shall use roller skates, skateboards, toys, on highways where play is prohibited” (Osberg et al., 2000, p. 7). The quality of path surfaces provided by cities can also

⁷ The survey was an option on the author’s skating website. Participants are those who happened to log on to the website and agreed to participate in the survey.

⁸ 741 observations were obtained for speed, 698 were obtained for sweep width, and 335 were obtained for stopping data (Birriel et al., 2001).

restrict skating (Osberg et al., 2000); for example, cobblestones, rough pavement, brick, wood, steel, and gravel surfaces all make skating extremely difficult (Osberg et al., 2000; Allingham and MacKay, 1997).

Crashes

The 2002 study based on data from the NEISS and the NSGA found that the injury rate for in-line skaters is 3.9 injuries for every 1,000 participants over the course of a year, which was less than half the bicycling injury rate (11.5 injuries for every 1,000 participants) (Kyle et al., 2002). Another study, based on more recent CPSC and the NSGA data, found that, when injury rates are considered per 10,000 days of participation, in-line skating injury rates (1.71) are only somewhat lower than bicycling injury rates (2.05) (U.S. Consumer Product Safety Commission, 2002b).

Locational Factors

A number of available studies use crash data to provide information on skating injury rates by location (Orenstein, 1996; Osberg et al., 1998; Allingham and MacKay, 1997; Frankovich et al., 2001).

One study (Orenstein, 1996) analyzed skating crash data from the Fairfax Hospital in Washington D.C. during the period from May 1992 to October 1993 (137 injuries, 63 of which were inline skaters and 36 of which were roller skaters). It was found that most inline skating injuries occurred on the street (34.9%) or the sidewalk (27.0%) and that most roller skaters were injured in a park or skating rink (50%) or the sidewalk (27.8%) (Orenstein, 1996).

Another study (Osberg et al., 1998) evaluated in-line skating injury data from the National Pediatric Trauma Registry over a 9-year period (October 1988 to April 1997). It found that most in-line skaters sustain injuries on the road (54.7%); however, most of these injuries were due to falls (72.6%) rather than collisions with motor vehicles (22.1%) or other causes (5.3%). This study did not provide specific information about sidewalk injuries.

One study analyzed skating injury data (893 cases in 1995) from the Canadian Hospital Injury Reporting and Prevention Program (CHIRPP) (Allingham and MacKay, 1997). The CHIRPP database consists of fifteen emergency hospitals, of which ten are pediatric hospitals and five are general hospitals. The authors found that in-line skating injuries occur most often on roads (36.5%) and footpaths/sidewalks (11.0%) (Allingham and MacKay, 1997). Most of the crashes were caused by loss of control (67.5%), but a few resulted from motor vehicle collisions (3.5%), surface conditions (5.0%), and collisions with either a stationary object or another person including cyclists (5.6%) (Allingham and MacKay, 1997).

Another study (Frankovich et al., 2001) analyzed in-line skating injury data from three emergency departments from three hospitals in Canada; the triage staff administered questionnaires to a total of 121 patients with in-line skating injuries from August 23, 1995, to November 19, 1996. Most of these injuries were sustained at parks (48.7%), and some were sustained on sidewalks (21.8%) and roadways (25.2%). The greatest contributing factors to injuries were loss of control (50%) and road hazards

(30.5%). Other factors were less significant, for example, conflicts with other skaters (5.9%), cyclists (2.5%), motor vehicles (2.5%), and pedestrians (0.8%) (Frankovich et al., 2001).

Human Factors

As described above, most skating injuries, regardless of the location, appear to be caused by loss of control because of skater error or poor surface conditions (Osberg et al., 1998; Allingham and MacKay, 1997; Frankovich et al., 2001). For example, Osberg and Stiles (2000) state that “the majority of skating injuries are due to forward falls on outstretched arms, without vehicle, bicycle, or other skater involvement” (Schieber and Branche-Dorsey, 1995; ctd. Osberg and Stiles, 2000, p. 229).

Again, younger individuals appear more likely to be involved in skating crashes. Allingham and MacKay (1997) reported that 59.6% of skaters injured were between ten and fourteen years old, followed by five to nine year olds (20.0%), and then by fifteen to nineteen year olds (14.9%). It is important to note, however, that the CHIRPP database over-represents pediatric hospitals and thus may over-represent crash rates among children. Frankovich et al. (2001) found that 50% of injured skaters were between eighteen and thirty-five years old and that 31% were younger than eighteen (Frankovich et al., 2001).

SKATEBOARDS

Background

In just over a year (from 1999 to 2000) the number of people who skateboard has increased to 11.6 million, according to the Sporting Goods Manufacturers Association (Bach, 2001). The sport is expected to have 15 million participants by the year 2005 (Williams, 2002). Skateboarding is typically considered to be a sport rather than a mode of travel. The sport typically attracts teenage and 20-something males (Bach, 2001). The current emphasis of the sport is on street skating or performing stunts and other tricks on skateboards (Williams, 2002).

Characteristics

It appears that no publications are available that provide measurements of the operational characteristics of skateboards.

Regulation

Although most skateboard for sport, some also use it for travel. In particular, college students often skateboard from class to class. However, because of safety concerns, some cities and college campuses have restricted skateboarding. In the city of Davis, California, skateboards are prohibited on sidewalks in central traffic districts. At the California State University in Long Beach, skateboards are prohibited “on all streets,

alleys, sidewalks, parking facilities, driveways, paths and grounds on the campus” (Engoy, 2000).

Crashes

When the crash rate of skateboarders appears to be relatively high. The 2002 study based on data from the NEISS and the NSGA found that 8.9 out of 1,000 skateboarders are injured over the course of a year (1998) (Kyle et al., 2002). Another study examined more recent injury data from the CPSC and the NSGA and found that, when injury rates are considered per 10,000 days of participation, skateboarding has the highest injury rate (2.51), following by bicycling (2.05), in-line skating (1.71), and scooters (1.03) (U.S. Consumer Product Safety Commission, 2002b).

Locational Factors

There is very limited evidence available on the location of crashes and contributing factors. The Orenstein (1996) study, described above, found that that skateboard injuries occurred frequently on roads (31.6%) and sidewalks (18.4%) and in other locations, such as indoor areas, parking lots, and driveways (36.8%). The author reports that an analysis of the NEISS database also found that “although 10% to 15% of skating injuries occurred in a street setting, only 0.3% to 3% of injuries were motor vehicle related” (Orenstein, 1996).

Human Factors

As with skating, loss of control appears to be the major cause of skateboarding crashes rather than conflicts with other roadway or non-roadway users. Orenstein’s (1996) analysis indicated that 51.3% of skateboarding injuries are due to excessive speeds, 17.9% to an obstruction, and 7.7% to motor vehicle collisions. There also appears to be some concern about the design of skateboards; they do not have a steering mechanism and so users may lose control more easily (Engoy, 2000).

Younger people, again, appear to be more likely to injure themselves on skateboards because of their lack of experience and ability. One study found that the mean age of injured skateboarders in this study was approximately 13.8 years old (Orenstein, 1996). A 2002 statement by the Committee on Injury and Poison Prevention reports that, according to the U.S. CPSC, 51,000 skateboard injuries involving skateboarders less than 20 years old occurred in the year 1999. The report also states that younger children are “at high risk of injury from skateboards and scooters” because of poor judgment, surrounding traffic (pedestrian or vehicular), and poor strength (p. 542). Moreover, younger children’s “center of gravity is higher than that of older children and adults, their neuromuscular system is not well developed, and they are not sufficiently able to protect themselves from injury” (Committee on Injury and Poison Prevention, 2002, p. 542).

SCOOTERS

Scooters in this section refer to the narrow, human powered devices that riders stand on, as opposed to the motorized scooters that are more like small motorcycles.

Background

People of all ages use scooters for a variety of purposes, including recreation and commuting (Eisner, 2000). Because it can collapse into a handheld unit, the scooter is convenient to use (Eisner, 2000).

The manual scooter typically consists of a baseboard, vertical T-bar to be used as handlebars, and small wheels located at the front and back of the baseboard. This type of scooter is also referred to as a “kick scooter”, “push scooter”, and “non-motorized scooter.”

Characteristics

Manual scooters are typically narrow in width. Razor kick scooters, for example, have the following unfolded dimensions: L26 x W14 x H35 inches (California Speed-Sports, Inc., 2002). The width of the scooter – 14 inches – when compared to a sidewalk width of 4.9 feet is relatively small. The speed of manual scooters range from 5 mph to 8 mph (Nova Cruz Product Inc., 2000; ctd. Levine et al., 2001).

Regulation

Scooter restrictions are similar to those of skating. For example, in Santa Rosa, California, one local ordinance prohibits scooters from sidewalks and streets in specified areas in the city (City of Santa Rosa City Council, 2001). The ordinance states that scooters, as well as other skating devices, pose a hazard to pedestrians and motorists because the user cannot change direction quickly, cannot maintain complete operational control of the device at all times, and can be easily obstructed from the view of pedestrians and motorists (City of Santa Rosa City Council, 2001). The popular scooter brands use wheels that are extremely similar to, if not the same as, in-line skates (Fry, 2003). These wheels allow for higher velocities but, like skates, they perform poorly on uneven surfaces (Fry, 2003) and their use is restricted by both regulation and available infrastructure.

Crashes

Scooter injury rates (3.1 out of 1,000 participants over a year) are not high relative to in-line skating, skateboarding, and bicycling (U.S. Consumer Product Safety Commission, 2002b). When injury rates are considered per 10,000 days of participation, scooter riding also has a lower injury rate (1.03) than skateboarding, bicycling, and in-line skating (U.S. Consumer Product Safety Commission, 2002b).

Locational Factors

One study analyzed data from the CHIRPP and found that, as of May 2001, there were 305 cases of scooter injuries, and 27.2% of those injuries occurred on the roadway and 67.2% occurred on non-roadway location (Injury Section [Health Canada], 2001). Approximately, 21% of scooter injuries were located on the sidewalk, either near or away from the home (Injury Section [Health Canada], 2001). Another study (Levine et al., 2001) found that, out of 15 children treated for scooter related injuries at the Pediatric Emergency Service of Bellevue Hospital Center from July 2000 through September 2000, 40% were located in a park, and 40% of the crashes occurred on the sidewalk. The U.S. Consumer Product Safety Commission, after conducting a study using telephone interviews of injury victims (injury victims found from NEISS database) from December 2000 to June 2001, found that most injuries are due to falls (75% out of 61,340 scooter injuries). Most of these falls occurred when the wheels hit something small such as a pebble or crack in the surface (27%) (U.S. Consumer Product Safety Commission, 2002b). Other contributing factors included falling when doing tricks (13%) and falling when trying to stop (9%) (U.S. Consumer Product Safety Commission, 2002b).

Human Factors

The few available studies indicate that conflicts are not a major cause of scooter injuries. One study found that most scooter injuries results from falls (87%) and only 6.7% resulted from motor vehicle conflicts (Levine et al., 2001). The study also found that the major cause of injuries was loss of control (59.0%), largely because of surface conditions (79.0%). Another study (Abbott et al., 2001) reports that the most frequent causes of injury were excessive speed, objects on pavement, and the inability to brake (Abbott et al., 2001). This study also describes the design characteristics of scooters that can lead to loss of control, falls, and injuries:

1. When riding the scooter, the rider's weight is positioned forward near the front wheel. Leaning on the handlebars to make a turn increases the risk of tipping over forward.
2. Pushing the scooter requires 1 foot on the footrest and the "push" foot on the ground. Should the scooter lean too far away from the push foot toward the opposite side of the body, the foot on the footrest stays where it is and cannot stabilize or stop the scooter from tipping over.
3. The scooter's wheels are small and close together, compounding the scooter's instability if it hits even a small obstacle on the street (e.g., a pebble, stone, or crack in the pavement). (Abbott et al., 2001, p.2 and 3)

Limited evidence is available on the typical age of injured scooter riders. One study found that eight to thirteen year-olds make up 76.4% of injured scooter users; however, pediatric hospital were disproportionately represented in this database (Injury Section [Health Canada], 2001). The U.S. Consumer Product Safety Commission (2002b) found that most injuries occur to children between 4 and 15 years old, and only a small percentage of users aged 20 and older are injured.

WHEELCHAIRS

Background

Wheelchair users in the U.S., outside of nursing homes, have increased from 720,000 in 1980 to approximately 2.2 million in the year 2000 (Seeman, 2000). In the near future, with the aging of the baby boomers, it is likely that the number of wheelchair users and their accessibility needs will grow at an even greater rate.

One important finding reported by many of the reviewed studies is that a large portion of people that need mobility devices cannot afford the device that best suits their needs or any device at all. For example, one 2000 report on mobility users in the U.S. comments that “about half of people or their families pay for devices solely on their own. The unmet need for devices is substantial, with the primary barrier being that people simply cannot afford to purchase them” (Kaye et al., 2000, p. 1). A 1999 article on manual and electric wheelchairs reports that “about 2.5 million people said that they purchased their assistive devices without the assistance of the third party payer and that they had unmet assistive device needs that they could not afford” (Cooper, 1999, p.27).

Characteristics

A number of studies describe the operational characteristics of wheelchairs. The 1999 FHWA design guideline for access states that wheelchairs (both manual and powered) have a width of approximately 2.5 feet and a turning radius that ranges from 2.1 feet to 4.2 feet (Axelson et al., 1999). Powered wheelchairs typically have a larger turning radius because they are longer than manual wheelchairs and thus require a 5 feet by 5 feet area to complete a 180° turn (Axelson et al., 1999). Both manual and powered wheelchairs usually travel faster than pedestrians, but are slower than pedestrians on uphill grades (Axelson et al., 1999).

Another study of fifteen electric powered wheelchairs (3 of 5 different models) found that the wheelchairs attained a maximum speed that ranged from 4.1 mph to 7.1 mph and could travel a distance that ranged from 16 miles to 20.1 miles on one charged battery (Wolfe et al., 2000).

Regulation

Many states consider wheelchair users to be pedestrians. For example, California law defines a pedestrian as someone “who is walking or using a human-powered device such as a wheelchair, skateboard, or roller skates” (American Automobile Association, 2003; Vehicle Code 467), and thus wheelchair users have the same rights and responsibilities as people walking.

The Americans with Disabilities Act (1990) requires that public areas and commercial businesses be accessible to disabled people. For example, the act states that “at least one accessible route within the boundary of the site shall be provided from public transportation stops, accessible parking, and accessible passenger loading zones, and public streets or sidewalks to the accessible building entrance they serve” (The

Access Board, 2002). More specifically, design guidelines state that sidewalks must have slopes that accommodate wheelchair travel, cross-slopes, or slopes that are “measured perpendicular to the direction of travel” should not have more than a 2% grade and the rate of change of a grade should not exceed 13% (Axelson, 1999, p. 35).

Crashes

Locational Factors

A few studies describe the locational factors that contribute to wheelchair injuries (Calder and Kirby, 1990; Kaye et al., 2000; Cooper, 1999). Calder and Kirby (1990) produced a report based on a search of the National Injury Information Clearinghouse database for any wheelchair-related fatalities from 1973 to 1987 (the entire time span of the database at the time the study was conducted) and found 770 wheelchair-related fatalities (Calder and Kirby, 1990). The National Injury Information Clearinghouse receives death certificates from state health departments and codes those that involve a consumer-related product. The study found that most fatalities occurred in institutions, private residences, or hospitals (90%), and that only 0.3% of fatalities occurred on the sidewalk. A number of the total cases involved a fall down stairs (6.6% of total cases); however, most of these cases were located in private areas such as institutions, homes, and hospitals (Calder and Kirby, 1990).

Kaye et al. (2000) evaluated the National Health Interview Survey⁹ and found that, compared to those using canes, walkers, and crutches (or mobility devices), wheelchair users and scooter users were more likely to have accessibility problems outside of the home (33.2% of wheelchairs surveyed and 34.1% of scooters surveyed).

Another study analyzed data from the NEISS database from 1986 to 1990 and found that of 2,066 nonfatal wheelchair incidents, tips and falls contributed to 73.2% of the cases, and “a secondary factor, such as a ramp” contributed to 41.4% of the cases (Unmat and Kirby, 1994, p. 32; ctd. in Cooper, 1999).

Human Factors

Several reports showed that falls and tips are the leading cause of wheelchair-related injuries and fatalities. One study found that, of 109 wheelchair users interviewed who sustained 253 incidents over the past five years, 42% of incidents were due to tips and falls (Gaal et al, 1997; ctd. Cooper, 1999). Another article analyzed 577 mail surveys of manual wheelchair users in Nova Scotia, Canada and found that 57.4% of the respondents “had completely tipped or fallen at least once”, and 66% of respondents reported having partially tipped (Kirby et al., 1994; ctd. Cooper, 1999). Calder and Kirby (1990) also found that 77.4% of fatalities in their study involved a fall or tip.

Older individuals appear to sustain wheelchair injuries more often than younger individuals because older people generally use the device more frequently. Calder et al.

⁹ This survey is “a national representative household survey conducted annually by the Census Bureau for the National Center for Health Statistics” that gathered data on the disabled community. The 2000 report also states that “respondents to the 1994 and 1995 NHIS also took part in two supplemental surveys, known collectively as the National Health Interview Survey on Disability (NHIS-D)” (Kaye et al., 2000, p.5).

(1990) found that eighty-one to ninety year olds appear to have the most fatal wheelchair-related crashes (38.6%). Kaye et al. (2000) showed that, out of 6,821 people that use assistive devices, 14.0% of them are sixty-five years old and older.

Additional Issues

It also appears that wheelchairs themselves are an important cause of injury to wheelchair users. Because of poor training and equipment, wheelchair users develop injuries such as rotator cuff damage (damage to the shoulder muscles), carpal tunnel syndrome, and wrist problems (Seeman, 2000). Technologically more advanced wheelchairs and scooters that minimize the risk of incurring such injuries are available; however, the cost of these devices is more than insurance companies are typically willing to pay. Thus, wheelchair users must either risk the possibility of injury or personally pay for a better unit.

One concern that wheelchair users have is the lack of wheelchair awareness and reform. Advancements such as electric wheelchairs and scooters are available; however, awareness and usage of these devices are comparatively low (Seeman, 2000). Doctors are not typically trained to provide wheelchair users with advanced wheelchairs (Seeman, 2000). Insurance companies opt for inexpensive wheelchairs that may cause injuries to the wheelchair user in the long run because the inexpensive wheelchairs are too heavy and ill-fitting (Seeman, 2000). It appears that wheelchair users are not properly trained to operate their wheelchairs, which is another cause of injuries (Seeman, 2000).

CONCLUSIONS

All low-speed modes, discussed in this paper, are used for “purposeful” travel to varying degrees; however, pedestrian, bicycle, and wheelchair modes are used more commonly than skates, skateboards, and scooters. Skates and skateboards are most frequently employed for recreational and sporting purposes. Scooters have only recently become popular, and thus little information is available on their pattern of use; however, the information that is available indicates that many children use them for recreational purposes.

Operational characteristics across the low-speed modes are described in Table 3. All the wheeled low-speed modes travel at significantly higher speeds than pedestrians. Bicycles and skates appear to travel at the greatest speeds and have the greatest space requirements for braking distance and/or turning radius. The space requirements for wheelchair turning are also significant.

TABLE 3. Operational Characteristics of Across Low-Speed Modes

Low-Speed Mode	Speed	Width	Braking Distance	Turning Radius
Pedestrians	2.7 mph	Not applicable	Not applicable	Not applicable
Bicycles	15 mph	3.3 feet	15 feet	56.3 feet
Skates	10.5 mph	4 feet	20 feet	Not available
Skateboards	Not available	Not available	Not available	Not available
Scooters	5 to 8 mph	14 inches	Not available	Not available
Wheelchairs	4.1 to 7.1 mph (electric)	2.5 feet	Not available	2.1 to 4.2 feet

The relative safety risks and more significant risk factors by low-speed mode are presented in Table 4. First, it can be seen that the risk of being injured while using a low-speed mode is relatively small (injury rate per 10,000 days of participation). Skateboarders have the greatest injury rate (2.15%), followed by bicyclists (2.05%), by skaters (1.71%), and by scooter riders (1.03%). Approximately, 0.1% of wheelchair riders are killed in crashes. Crash rates are not available for pedestrians.

Second, it appears that most low-speed mode crashes do not involve collisions with other low-speed modes or motor vehicles (when data is available). Most crashes involve the low-speed mode only (63% to 80%). For pedestrians, 63% of crashes involve pedestrians-only, 36% involve motor vehicles, and 1% involve bicycles. For bicycles, 67% involve bicycles-only, 29% involve motor vehicles, 3% involve other bicycles, and 2% involve pedestrians. For skates, 80.5% of crashes involve skaters-only, 5.9% involve other skaters, 3.5% involve motor vehicles, 2.5% involve bicycles, and 0.8% involve pedestrians. Data were not available for skateboards, scooters, and wheelchairs.

Third, not surprisingly, frequency of crashes in the non-road and road environment appears to be related to the frequency with which the low-speed mode uses the environment. Typically, location use follows from regulation of the mode. For example, regulations discourage bicyclists from using the sidewalks. Most pedestrian crashes occur in the non-road environment (48%), and most of these crashes occur on the sidewalk. When pedestrian crashes do occur on the road environment (43.4%), it is most commonly where sidewalk pedestrian travel meets the road (e.g., intersections). Bicyclists are most often injured in the road environment (58.3%) on intersections and driveways and less often in the non-road environment (26.4%). Most of the crashes in the non-road environment are bicycle-only crashes on sidewalks. In-line skaters are most often injured on roads (34.9%) and sidewalks (27.0%). Roller skaters are most frequently injured in parks/rinks (50%) and on sidewalks (27.8%). Skateboard crashes occur most often in indoor areas, parking lots, and driveways (36.8), sidewalks, (18.4%), and roads (1.6%). Scooter crashes are most common in the non-road environment (67%) on sidewalks (21%) and on roads (27.2%). Wheelchair crashes rarely occur on sidewalks (0.3%); most occur indoors (e.g., hospitals or institutions).

Fourth, the most common risk factors for low-speed mode crashes are surface conditions, user error (e.g., excessive speeds or wrong-way travel), motor vehicle driver error, obscured driver vision, and device design characteristics (e.g., inability to brake).

Finally, the young are most commonly injured in low-speed mode crashes, with the exception of wheelchairs. It appears that younger people use low speeds modes more often. In addition, the young are frequently less experienced and have poorer judgments and may make more errors when operating the devices. The design of skateboards and scooter appears to make use by children more dangerous.

This preliminary study of the safety of low-speed modes has two important implications for the proposed pilot project that introduces shared Segway HTs, electric bikes, and bikes linked to a suburban Bay Area Rapid Transit (BART) District station and employment centers in Northern California. First, the results of the literature review suggested that user error was a major cause of crashes for low-speed modes, and thus extensive training will be required of pilot participants to ensure that user error is minimized. For example, issues of particular concern that will be addressed are transitioning from paths to roadways at crosswalks and intersections, wrong way travel, and dangers of driveways. Second, the results of the literature review indicated that poor surface conditions were a significant contributing factor for low-speed crashes, and thus the paths included in the pilot will be carefully selected to maximize surface condition quality. Training will also include practice and instruction on the best ways to handle more challenging surface conditions.

TABLE 4. Relative Safety Risks and More Significant Risk Factors by Low-Speed Modes.

Low-Speed Mode	Injury Rates	Regulated Location	Frequency of Crashes Type	Frequency of Crash by Location	Common Risk Factors	Commonly Injured Age Group
Pedestrians	Not Available	Sidewalks	Only: 63% MV: 36% Bike: 1%	Nonroad: 48% -sidewalk Road: 43.4% -intersection -no crosswalk	Only: surface conditions MV: pedestrian & driver negligence	Young
Bicycles	2.05 per 10,000 days of participation	Sidewalks use discouraged	Only: 67% MV: 29% Bike: 3% Ped: 2%	Road: 58.3% -intersection (sidewalk bikers) -driveway Nonroad: 26.4% -most are bike only on sidewalk	Only: surface conditions MV: wrong way bike travel & obscured driver vision	Young
Skates	1.71 per 10,000 days of participation (in-line skating)	Some bans on sidewalks	Only: 80.5% Skaters: 5.9% MV: 3.5% Bike: 2.5% Ped: 0.8%	In-Line: -road: 34.9% -sidewalk: 27.0% Roller: -park/rink: 50% -sidewalk: 27.8%	Surface conditions Collisions	Young
Skateboards	2.51 per 10,000 days of participation	Some bans on sidewalks	Not available	Other (indoor areas, parking lots, and driveways): 36.8% Sidewalks: 18.4% Roads: 1.6%	Excessive speeds: 51.3% Obstructions: 17.9% Collisions with MV: 7.7%	Young
Scooters	1.03 per 10,000 days of participation	Some bans on sidewalks	Not available	Non-road: 67% -most on sidewalks: 21% Road: 27.2%	Surface conditions Excessive speeds Inability to break MV conflict	Young
Wheelchairs	7.6 fatal per 100,000 users per year (Caulder and Kirby, 1990)	Sidewalks	Not available	Sidewalk: 0.3% Most occur inside	Tips and falls Ramps	Elderly

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