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Child Pedestrian Injury: A Review of Behavioral Risks and Preventive Strategies

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Abstract

Pedestrian injury is among the leading causes of pediatric death in the United States and much of the world. This paper is divided into two sections. First, we review the literature on behavioral risk factors for child injury. Cognitive and perceptual development risks are discussed. The roles of distraction, temperament and personality, and social influences from parents and peers are presented. We conclude the first section with brief reviews of environmental risks, pedestrian safety among special populations, and the role of sleep and fatigue on pediatric pedestrian safety. The second section of the review considers child pedestrian injury prevention strategies. Categorized by mode of presentation, we discuss parent instruction strategies, school-based instruction strategies (including crossing guards), and streetside training techniques. Technology-based training strategies using video, internet, and virtual reality are reviewed. We conclude the section on prevention with discussion of community-based interventions.

Keywords

pedestrian injury; children; road crossing; route selection; review

Pedestrian injury is among the leading causes of pediatric death in the United States [US] and much of the world.[1,2] Among children ages 4–12 in the US, 2007 data indicate 17,342 serious injuries and 219 fatalities from pedestrian injury.[1] This places pedestrian injury as the third-leading cause of injury-related death for both boys and girls aged 5 to 14 in the US.[3] Recent economic estimates suggest pediatric pedestrian injuries cost almost $300 million dollars for inpatient hospital treatment alone.[4] Although all children are vulnerable, boys are more often the victim of pedestrian injuries (64% of US fatalities in 2007), as are children who are Caucasian (71% of US fatalities) or African American (26% of US fatalities).[1]

As children develop, specific pedestrian injury risks change. Toddlers (ages 1–2) are most likely to be injured in driveways, where drivers moving backward are unable to see them.[5,6] Adolescents are at risk due to walking at night with poor visibility, walking while intoxicated, walking while distracted by phones, and other reasons.[7] This review focuses on children between those two phases, ages 4 through 12. During this stage of development, most pedestrian injuries occur in mid-block areas, where children enter into the middle of the street and are struck by moving vehicles, or at intersections.[8–11] In some cases, incidents are "dart-out" situations where children enter the street quickly, without thought, to chase a person, toy, or pet, or to meet someone or something on the other side of the street. In other cases, the incidents are the result of poor judgment by the child; he or she believes it to be safe, and enters the street when in fact the situation is not safe.

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Pedestrian injuries are caused by a wide range of factors. This review focuses on behavioral factors, or those related to human behavior of the pedestrian and others around him or her. In doing so, we acknowledge the importance of other variables that impact pedestrian safety risk and prevention of pedestrian injury. These include aspects of the road environment, traffic engineering, vehicle engineering, and the time of day and season of year.

We conducted the literature review using three steps. First, we searched both the PscyINFO and Pubmed databases for relevant articles using the following search: [(pedestrian or street) in title] AND [child* in abstract] AND [(safety or injur*) in abstract]. Second, we followed references in those articles. Third, we searched our personal libraries. Articles about road, traffic, and vehicle engineering; post-injury functioning; and other non-behavioral aspects of pedestrian injury were not included. Together, these strategies produced over 100 relevant manuscripts, which are reviewed below in two sections: (a) a review of risk factors for child pedestrian injury, and (b) a review of effective intervention and prevention programs.

Risk Factors for Child Pedestrian Injury

Developmental Factors

Cognitive Development—Safe pedestrians must possess and utilize advanced cognitive skills.[12,13] A large body of research suggests that children's development of cognitive skill is related to increased pedestrian safety and that relevant skills improve as children get older.[12,14–16] Of course, it is not a single cognitive skill that influences safety. Instead, it is the combined development of a number of different cognitive processes that are linked to safe pedestrian behavior. Those processes also overlap with other developing skills, such as perceptual and motor abilities. Below, we address several cognitive skills relevant to safe pedestrian behavior.

First, safe pedestrians must have strong attentional processes. Attention is relevant for a few reasons. Pedestrians must recognize what should be attended to in order to preserve safety. A safe pedestrian must realize, for example, that oncoming traffic is important but traffic that has already passed is much less so. Young children may not attend to the relevant stimuli in traffic situations.[17] Beyond recognizing what stimuli are important, safe pedestrians must also attend properly to those stimuli that have been identified as important. In particular, pedestrians must watch traffic moving from both directions. They must also, in most settings, attend to other external stimuli such as traffic turning or moving across intersections, emergency vehicles, barriers to vision of vehicles, and a number of other possible relevant stimuli. Laboratory-based research suggests children with better concentration and attention skills may be safer pedestrians, perhaps because they better manage the multiple stimuli that must be attended to.[18,19]

A second cognitive skill that safe pedestrians must develop is information processing. Beyond simply attending to stimuli, the pedestrian must process information about the stimuli that are perceived. In particular, pedestrians must piece together the various pieces of information that are perceived, almost as if they are assembling a multi-piece moving jigsaw puzzle in their heads. To take a fairly simple example, imagine a child crossing a two-lane, bidirectional street at a mid-block location. To accomplish this crossing safely, the child must estimate when a vehicle on the right will pass, but simultaneously anticipate what will be occurring from the left after the vehicle from the right passes. Two pieces of data–the vehicle from the right and the vehicle from the left–must be considered either simultaneously or sequentially (but, if sequential, in very rapid sequence). Of course, most pedestrian situations are much more complex. There may be other vehicles and other directions to consider. The pedestrian must also consider the distance across the street, and the speed with which he or she could cross that distance. Thus, processing of information is

a critical cognitive task of pedestrian behavior. Some have labeled this ability "attention-switching"[18] or "selective attention".[20] The essence is that a safe pedestrian must manage to perceive, attend to, and process multiple sources of stimuli within a very short time period. Young children struggle to do so safely.

A third cognitive task required of safe pedestrians is decision-making. When a safe gap in traffic appears, children must not only recognize the safety of that gap but decide very efficiently–in the course of milliseconds–that they should initiate crossing by stepping onto the roadway. Safe traffic gaps often are fleeting; if a decision is postponed even briefly by mental deliberation, safety will be sacrificed. Thus, strong and efficient decision-making skills must be in place before children can safely utilize their other cognitive skills to engage in safe pedestrian behavior. There is replicated evidence, for example, that younger children take longer to enter a safe traffic gap than do older children.[16, 21–23] On many occasions adults actually anticipate a safe gap in traffic before it arrives–they enter the near lane of traffic just as a vehicle passes in the far lane, anticipating that the far lane will be vacant by the time they enter it as a pedestrian.[14]

Researchers have not yet determined exactly what cognitive processes might delay entry into safe gaps by younger children. A leading hypothesis is that it reflects processing speed and decision-making. Younger children may take longer to process the stimuli they perceive and then take longer to consider and make a decision about crossing.[16,22] Another possibility should be considered, however - that the delay reflects translation of a decision into motor initiation or in determining how quickly motor behavior can be initiated.[22] Younger children may take longer to translate a decision into physical movement of the legs. Future research should investigate these and other possible explanations for the consistent finding of delayed initiation of entry into traffic gaps by younger children.

A final cognitive task required of safe pedestrians has not to do with actually crossing a street, but instead choosing where and how to cross. In selecting a safe route across a street, children must consider the risks of mid-block or diagonal crossings versus crossing at marked crosswalks and/or at intersections.[24,25] They must recognize the risks of crossing near occluding parked vehicles versus at locations where the view of oncoming traffic is clear.[26] Deductive reasoning skills and memory for rules are important to making safe decisions with these sorts of situations. Younger children (roughly ages 5–8) have more trouble selecting safe traffic routes than older ones (roughly ages 9 and older).[24–26] Two studies report links between safe selection of routes to cross streets and attention and speed of processing skills.[27,28]

Perceptual Development—Along with cognition, safe pedestrians must accurately perceive the environment they engage within. By toddlerhood, most children have the physical capacity to see and hear traffic. Even peripheral vision for stimuli like traffic, which develops somewhat later, is fully developed to near-adult levels by age 7.[29] Thus, simple identification of moving vehicles is not usually the perceptual challenge to safe child pedestrian behavior. Instead, more complex aspects of perception are problematic. A safe pedestrian must not only recognize oncoming traffic, but must judge vehicle speed and acceleration/deceleration in order to estimate when the vehicle might arrive at the crossing area. Children are not skilled at these estimations.[15, 30, 31] Some research suggests children tend to notice vehicle presence and distance, but do not consider speed or distance of the oncoming vehicles.[15] Others have found that children underestimate the time until a vehicle will arrive, not reaching adult capacity until about age 12.[32]

Safe pedestrians must also have advanced visual search skills.[33] They must be able to search the street environment to detect and then respond to potential dangers. Whitebread and

Neilson[33] reported that such skills develop with age, with many children achieving a strategic shift in visual search ability around age 7 or 8. They also found links between visual search skills and pedestrian safety among children.

Of course, cognition and perception overlap closely. Safe pedestrians must recognize when their perception is impaired. This is a cognitive task involving perception. Parked cars and shrubbery can block vision of approaching vehicles, particularly for children who have shorter stature than adults. Road features also can impair perception. Traffic can be difficult or impossible to see if the road bends or curves. Inclines can alter vehicle acceleration/deceleration patterns in challenging ways, and pedestrians must perceive and then process those changes. A small literature indicates development between ages 6 and 10 improves children's ability to handle the task of perceiving safety around physical barriers.[26]

One final aspect of perception for safe pedestrian behavior is aural perception. The small amount of existing research on auditory perception of traffic sound suggests there are developmental influences on ability to interpret meaning in vehicle sounds, and that young children (age 5) have poor skills.[34] However, most work has focused on visual perception in the pedestrian environment, and future research should address the role of auditory perception in greater detail.

Distraction

Even when children have the cognitive and perceptual development to be safe pedestrians, their safety might be jeopardized if they are distracted while crossing streets. The automobile safety literature has long recognized the risk of distraction while driving a motor vehicle, but research concerning the effect of distraction on child pedestrian safety is less developed.[35–37]

As reviewed above, laboratory findings suggest attention and distraction play a role in children's pedestrian behaviors.[18,28] A few studies have looked specifically at behavior of distracted pedestrians. Among adults, observational research suggests adult pedestrians talking on mobile phones[38,39] or broadly distracted by eating, drinking, smoking, or talking[40] take somewhat greater risks than those who appeared to be undistracted. A recent study replicated this finding among adults crossing in a virtual pedestrian environment while talking on the phone.[41] Interestingly, listening to music appears not to distract adult pedestrians.[39, 41]

Just one published study has considered the specific role of distraction on child pedestrians.[42] A sample of 10- and 11-year-old children crossed an immersive and interactive virtual street 12 times, half while talking on a phone and half while undistracted. Talking on the phone caused significant increases in risk-taking and significant decreases in safety while crossing the street.

Temperament and Personality

Children's pedestrian safety is likely influenced by individual differences in temperament and personality.[14, 43, 44] Barton and Schwebel[14] found that 5- through 8-year-olds rated by their parents as having less behavioral control took more risks in simulated pretend road crossings. Hoffrage and colleagues[44] reported similar results among 5- and 6-year-olds classified as risk-takers by a simple risk-taking game who were later observed in a simulated roadside crossing.

Social Influences

Parents—Not surprisingly, parental supervision appears to protect children from pedestrian injury risk.[14, 45–47] In one study of 142 children ages 5–12 treated at Children's Memorial Hospital in Chicago for pedestrian injury,[46, 47] families reported that 64% of the victims were unsupervised at the time of injury. Of the 36% who were supervised, some were supervised only by teenagers (not adults). Others were supervised by an adult who was physically a substantial distance away (e.g., on the porch, while children played in the yard, near the street).

Barton and Schwebel[14] studied the effect of supervision on 5- through 8-year-old pedestrians via an experimental design and reported a similar trend. Children crossed a simulated crosswalk immediately adjacent to a real road with traffic. Children physically crossed the simulated pretend road when they felt it would be safe to cross the real road, based on actual traffic passing by. In a within-subjects design, parents were positioned in one of four locations while children crossed: (a) completely out of sight, (b) within sight but behind a window and unable to communicate with child, (c) on the opposite side of the simulated street, and able to communicate through yelling or hand motions, and (d) with the child. As intensity of supervision increased, so did safety of children's crossings.

The positive influence of parental supervision is particularly troublesome in the context of research on parental attitudes and practices with regard to child pedestrian safety. Parents tend to believe their children are safe pedestrians and allow their children to walk alone on streets, despite the fact that they recognize the limitations of child pedestrian skills.[48–50] They also do not spend significant time teaching their children safe pedestrian skills[49,51] or modeling safe pedestrian skills for their children[52] (though see other work[53] for contradictory data on modeling).

Peers—Crossing streets with peers appears to increase risk of pedestrian injury.[46] Research in other domains suggests the presence of peers causes children to make riskier decisions and to exhibit riskier behaviors,[54–56] so it is not surprising that those tendencies might translate to pedestrian environments. In the Wills and colleagues sample in Chicago, for example, 68% of pedestrian injuries occurred with peers present.[46] This rate may be quite a bit higher than the rate of walking with peers; in one study, for example, only 28% of 5- through 9-year-olds walked to school with peers.[57]

Environmental Risks

The type of environment a child pedestrian walks within impacts pedestrian safety in multiple ways. Perhaps the most critical risk factor is the population and traffic density of the area. Greater exposure to traffic leads to greater pedestrian injury risk, so children in urban, high population and high traffic density areas are more likely to experience pedestrian injury than those in less populated areas.[57–63] A secondary consequence of this is that children from lower socioeconomic status backgrounds tend to have higher injury rates: urban dense environments tend to be communities where individuals with lower income and lower socioeconomic status levels live.[64,65]

Also relevant to child pedestrian safety is the placement of schools and recreational or play areas for children. Children are more likely to be hurt near schools,[11,66] presumably because exposure rates are higher. Similarly, homes with an adjoining play area have lower pedestrian injury risk, probably because children who lack immediate access to a play area are more likely to play in driveways and streets, or to walk to play areas.[62] Areas with mixed uses (residential, commercial, and industrial) also lead to increased risk, perhaps

because of the greater presence of heavy equipment and heavy-duty trucks that have reduced vision and mobility.[60]

Special Populations

Relatively little published work addresses the topic of pedestrian safety among special populations of children. One broad epidemiological study found that children with a range of physical, mental, sensory, or self-care disabilities were more likely than children without disabilities to have experienced a pedestrian injury.[67] Among specific populations, researchers have suggested that visual or auditory impairments might influence pedestrian safety, with visual cues more essential than auditory ones.[68]

One unpublished doctoral dissertation examined the role of Attention-Deficit Hyperactivity Disorder (ADHD) on pedestrian safety, hypothesizing that the high rates of impulsivity, poor concentration, and inattention associated with ADHD might place those children at risk for pedestrian injury. Using a case-control design with 39 children with ADHD-Combined type and 39 typically developing children matched by age and gender, children crossed a virtual pedestrian environment. Those with ADHD chose riskier environments in which to cross, left less amount of time between safely crossing the street until the next car arrived, and were hit more often by virtual cars.[69]

Sleep and Fatigue

Several of the same characteristics that influence pedestrian safety–reaction time, impulsivity, risk taking, attention, and decision making–are negatively influenced by sleep deprivation.[70–73] Sleep restriction has been associated with increased broad unintentional injury risk in children,[72, 74, 75] but to date we are unaware of definitive empirical research indicating fatigue or sleep deprivation might lead to pedestrian injury risk.

Prevention

Child pedestrian injury rates are declining in many places, including the US. Most professionals seek continuing declines, and more rapid declines, but the trajectory is encouraging. There are a number of explanations for the trend. One leading explanation is that children simply are not walking as often as they had in the past, so there is less exposure to pedestrian injury risk (this explanation has a corollary, of course, that reduced walking may contribute to rising child obesity rates). A second explanation is the success of multiple prevention initiatives implemented by a range of stakeholders. A few previous reviews of pedestrian safety intervention programs are available;[76– 79] this review supplements and extends those reports.

Pedestrian Safety Instruction by Parents

Given the amount of time they spend with children, parents are perhaps in the best position to train children in safe pedestrian behaviors. Unfortunately, available research suggests parents do not use the opportunities they have to teach children pedestrian safety. In one study in Scotland, 123 adult-child pairs were observed crossing the street. Although parents generally practiced safe behavior (98% of pairs crossed within the crosswalk, for example, and 81% waited for the lighted walk signal), only 6% of parents were actually talking to their child while crossing, indicating almost none were using the opportunity to teach the child about street-crossing safety.[51]

When parents are specifically guided to train children in pedestrian safety, the training does appear to be effective, even among young children. In one study, for example, 307 children ages 4 to 6 were randomly assigned to receive pedestrian safety training by parents,

pedestrian safety training by an experienced assistant and audiovisual demonstrations, or to a no-training control group.[79] Post-training, pedestrian safety knowledge in both groups of children who received training was equivalent, and both trained groups had superior knowledge levels to the control group. Thus, parents who are guided to teach their children are fully capable of effective training.[79] Other studies have shown that parents can effectively teach other children (that is, not their own children) as well.[80,81]

Taken together, it appears that parents generally practice (and therefore model) safe pedestrian behavior in front of their children and can serve as effective pedestrian safety instructors, even to younger children (ages 4-6), when they make the conscious effort to provide instruction. Unfortunately, parents do not regularly teach their own children pedestrian safety skills.[49,51] One public health campaign that might prove effective would be increasing parental recognition that pedestrian safety training is possible, simple, and effective–and therefore should become a standard part of parenting children during the preschool and early elementary school years.

Pedestrian Safety Instruction by Schools

Besides parents, schools offer an excellent setting for pedestrian safety training. Children are accustomed to learning in schools, and a large portion of pedestrian injuries occur near schools, as children travel to and from them.[11,66] Schools also offer the obvious advantages of large numbers of children gathered together in the same place and qualified educators in that same location.

A few early studies established the promise of school-based training programs.[82,83] In one, an extensive instructional package, including both classroom and streetside components, was delivered to students in grades kindergarten through 3 and yielded significant change in skill levels post-training, plus retention of change a year later.[82] A second large study used similar strategies with 6- and 7-year-olds and demonstrated a reduction in actual injury incidents in target areas.[83] A subsequent study tested the inclusion of a parent component along with an 8-session school-based training program for children in grades kindergarten through 4.[84] Positive changes in behavior were noted among all children, but those children exposed to both the parent and school-based component rather than just school-based training had greater increases in safe behaviors.

More recently, several large-scale programs have been tested. They have achieved mixed success. Below, we discuss three of the most carefully evaluated ones: WalkSafe, Child Pedestrian Injury Prevention Project (CPIPP), and Cyrus the Centipede. We then conclude with a discussion of a few trials of short-term/single-session school training programs on pedestrian safety.

The WalkSafe program is designed to teach pedestrian safety skills to children in kindergarten through 5th grade. Originally developed for use in Miami-Dade County, Florida, it is currently used broadly in the US and elsewhere. WalkSafe, which is standardized by age group, employs experience in an imaginary road, videos, educational materials, and workbooks to teach appropriate pedestrian behavior.[77, 85, 86] It involves about 2.5 hours of interactive, experiential, and classroom training. Hotz and colleagues[85,87] examined the efficacy of this program in 16 elementary schools. Results showed a significant increase in pedestrian knowledge between pre- and post-intervention testing for all grade levels and a significant improvement in some observed behaviors from pre- to post-test among a smaller sub-sample of children. Most learned knowledge was retained over a 3-month follow-up period.

The CPIPP program is a comprehensive pedestrian safety education program that incorporates lessons at both home and school, as well as community-based initiatives to reduce driver speeding and decrease child risk-taking.[88–90] Developed in Australia, a primary objective is to teach families that 6- to 9-year-olds should not cross streets without adult supervision. A quasi-experimental research study was conducted in three communities near Perth. Results suggested the program was moderately successful at both increasing children's knowledge about pedestrian safety and reducing risky pedestrian behaviors.[89,90]

Cyrus the Centipede was developed by the National Safe Kids Campaign in the US to teach 5- through 8-year-old children pedestrian safety. It encompasses five interactive lessons for teachers to incorporate into their classroom curriculum. In a case-control study with 126 third-grade students, children's pedestrian safety knowledge and self-reported pedestrian behaviors were collected at baseline and again one week later, following delivery of the intervention to 79 of the 126 children.[91] The intervention resulted in positive changes in knowledge and behavior compared to children in the control group, especially in some classrooms. The authors concluded that the intervention could be effective if administered skillfully, but warned that the impact of the intervention is dependent on how it is delivered.[91]

Finally, three recent studies have examined the potential of short-term school-based training programs. Morrongiello and Kiriakou[92] evaluated the impact of Pee Cee Herman, a 30 minute interactive program delivered by a police officer to first graders. They found improved pedestrian safety knowledge among the sample of 142 children both immediately post-training and in a follow-up evaluation 2 months later.[92] Albert and Dolgin compared three brief school-based training lessons: training with a table-top model, training with a 9-verse song, and training via listening to a story on pedestrian safety.[93] A sample of forty 4- and 5-year-olds was randomly assigned to conditions and exposed to four 15-minute training sessions over the course of four weeks. Results demonstrated moderate improvement in knowledge, behavior in a table-top simulation, and behavior on an actual (protected) street crossing. The table-top model training appeared to be most effective.[93] Others achieved similar result using a table-top simulation game.[94]

One other brief school program focused on safe route selection to cross streets.[95] Three commercially-available intervention programs –training using three-dimensional diagrams of pedestrian environments, training using street safety board games, and training with posters and flip-chart materials–were evaluated among 120 four- and five-year-olds. All three pedestrian safety interventions were found to increase children's knowledge about safe pedestrian behavior, but none resulted in improvement in actual pedestrian behavior among the children.[95]

Taken together, it appears that school-based training programs have some potential to teach children safe pedestrian skills, but only if they are well-designed, delivered in an effective manner, and delivered at a developmentally appropriate level. School-based training programs may not be the most efficient or universally effective strategies to train children pedestrian safety skills.

Crossing Guards

Beyond training in the classroom, many schools utilize crossing guards (experienced pedestrians who stand along the street to aid children) for the combined purposes of maintaining child safety while crossing the street and training children on safe crossings. Research suggests crossing guards are effective at both objectives. By shepherding children to cross when it is safe, they help children maintain their safety. They also serve as models, demonstrating safe behavior, providing praise for safe pedestrian behaviors, and correcting

unsafe behaviors when needed.[82] Research suggests crossing guards do not need to be professionals such as police officers or teachers. Instead, almost any mature pedestrian with some minimal training, including even older children or teenagers, can provide proper training and feedback to children.[82,96]

Streetside Training

Several studies have examined the efficacy of one-on-one or small-group pedestrian safety training at streetside locations. Some have considered training for crossing streets, and others training for safe route selection.

Streetside training designed to improve crossing safety is generally effective for children as young as age 5[97–99] and yields short-term improvement in safety of crossing. With minor variations, the training involves repeated practice with feedback from an adult on the child's decision-making. The evaluated training programs were brief in duration. One study re-tested the children ten weeks later and found some loss of skills that had been learned, thus raising questions about long-term retention of skills learned through this strategy.[98]

Two published studies have investigated the use of streetside training to improve children's pedestrian route selection.[99,101] In both, five-year-old children were exposed to training either at streetside locations or using a table-top model. One study used individualized training and the other small group training (groups of five children). In both cases, training was comprised of six sessions, lasting approximately 30 minutes each. Results generally suggested that the training was effective, and children chose safer routes following training either streetside or with tabletop models.[100,101] Lessons were retained fairly well over a two-month follow-up period. Results were also replicated with older children.[100]

Video and Internet Training

One major drawback to individualized pedestrian safety training is that it is highly time-and labor-intensive, and therefore unrealistic for broad implementation in school or community center settings. For this reason, interventionists have searched for other strategies to teach children pedestrian safety –and especially for training strategies that will not require intense adult supervision of children in dangerous settings.

An early solution to this problem was to train children via videotapes. Preusser and Lund[102] found, for example, that fourth- through sixth-graders who were exposed to a pedestrian safety film had increased knowledge of pedestrian safety and modestly improved behavior in observed street-crossing near their schools. Others studying younger children have found contrary results. Using a pre-post case vs. control design with a group of 5-year-old children, Zeedyk and Wallace[103] examined the efficacy of a popular Scottish television program designed to teach pedestrian safety. They found that children exposed to the video had no improvement in knowledge of the lessons presented in the program, nor did they have greater knowledge than the control group. Importantly, Zeedyk and Wallace[103] also asked parents of the children whether they thought the video was helpful; parents inaccurately thought their children had learned by watching the video.

More recently, research has focused on the efficacy of computer-based training programs. Several popular internet-based pedestrian education websites have emerged (e.g., Otto the Auto at http://www.ottoclub.org/; Safer Journey at http://safety.fhwa.dot.gov/saferjourney/journey/index.htm), but published reports about their efficacy are unavailable. Available work has focused on non-internet-based educational games designed to teach children pedestrian safety. In one, Tolmie and colleagues used a set of computer-based games, in conjunction with adult- or peer-discussion, to teach 5- through 8-year-old children how to identify safe gaps in traffic.[104] Children who were exposed to the game along with adult

discussion demonstrated the most learning; any exposure to the game was superior to control children who did not play the game. There were no tests of translation to real-world environments.

In a second study, Glang and colleagues examined the efficacy of WalkSafe, a CD-ROM designed to teach children the various components for pedestrian safety in an interactive, multi-media format.[105] Children in kindergarten through third grade participated, and results showed substantial improvement in knowledge of pedestrian safety among the sample following use of the program. Again, no tests of translation to real-world environments were included.

Taken together, initial evidence suggests both videos and interactive computer games may be effective pedestrian safety training strategies, especially among children over age 5. Further research is needed.

Virtual Reality

A few research teams have experimented with the use of virtual reality to train children in pedestrian safety.[106–109] Virtual reality offers several advantages over other training options. Most critically, it offers the opportunity to place children in a potentially dangerous environment without the risk of that environment. Repeated practice without adult supervision is feasible.

Early published reports using virtual reality to train children in pedestrian safety are promising.[106, 107, 109] All were conducted in non-immersive virtual environments, and all found the training improved children's safety. In one, for example, children in grades 4–6 engaged in a 3-monitor desktop display of a pedestrian environment.[107] A pre-post design was used at two schools. Feedback about virtual crossings was provided by an adult experimenter standing adjacent to children. Real-life risk-taking was observed both prior to and after training, as children walked in front of their school. Results found that children performed significantly better in a post-training virtual trial than they did pre-training. At one of the two schools, researchers also observed an increase in real-life safety while crossing streets near the school.

A second study utilized a virtual pedestrian environment displayed on a single computer screen.[109] Children ages 7, 9, and 11 were exposed to four sessions of training, each for 30–40 minutes and scheduled a week apart from the previous session. The virtual environment allowed children to choose safe gaps to cross within and offered computerized feedback of safety of crossing. Children's mothers supported the training and provided verbal feedback to supplement learning in the virtual world. Pre-post comparisons demonstrated significant learning as a result of the training, and a follow-up evaluation 8 months later demonstrated retention of the learned material over time.

One other research team utilized a virtual environment displayed on a single computer monitor.[106] In a case-control design, a small sample of children ages 7 to 12 were randomly assigned to training in pedestrian safety within the virtual environment or training using computer games. Training in the virtual environment was conducted for up to three sessions lasting a maximum of 20 minutes; the duration and number of sessions depended on the rate of learning. Children were finished after they had mastered the virtual task without being hit by virtual vehicles. Results suggested that children trained in the virtual environment demonstrated safer behavior both in a real environment and in the virtual environment; children in the control group did not demonstrate those changes.

Altogether, a small body of literature suggests virtual reality offers an excellent mechanism to train normally-developing children in pedestrian safety. Preliminary work also indicates promise for training children with autism[110] and adults who have had a stroke[111] in pedestrian safety. A large randomized controlled trial is currently ongoing to provide a more elegant test of training normally-developing children in a virtual environment.[108] That trial will evaluate training within an interactive and immersive virtual environment, rather than a two-dimensional one; and will compare training in a virtual environment to individualized streetside training, training using videos and computer games, and a no-contact control group in a sample of over 200 children ages 7 and 8.

Community Interventions

Beyond intervening at the individual child level, some work has examined community-level interventions to improve child pedestrian safety. As an example, Preusser and Blomberg examined the effect of public education on child pedestrian accidents.[112] The study implemented an in-class film, posters, and television commercials to inform children of the importance of stopping at curbs or the outside edge of parked cars and looking left, right, then left for cars before crossing the street. Both pre- and post-intervention, students in grades K through 6 were surveyed about their pedestrian safety knowledge and were observed crossing streets after school. Results showed that children were more knowledgeable about pedestrian safety after the public education intervention and that children displayed safer pedestrian behaviors when crossing streets.[112]

One program that has become widespread recently, especially in England and New Zealand, is the Walking School Bus. This program involves adult volunteers who are responsible for walking with groups of children while looking for potential dangers and maintaining order within the group. There are usually at least two adults present: one at the front called the “driver” and one at the back called the “conductor.” These adults stay with the children from the school until the final “stop,” when children are left at their homes; children are only allowed to leave the walking school bus at a “stop”.[113] Experimental and quasi-experimental research identifies several advantages with the walking school bus. These include decreased number of vehicles on the road, increased health benefits due to walking, and safer walking environment since research exhibits less risk when walking with large groups of people.[114–117] Unfortunately, these programs have mainly been established in areas with a higher socio-economic level, despite the higher rates of pedestrian injuries in areas of lower socioeconomic status.[118]

One final example of a large community initiative to teach children safe pedestrian skills is Kerbcraft, which was developed in Glasgow and is used widely in the United Kingdom. In this program, community volunteers –often retired individuals –teach children ages 5 to 7 through 12 roadside training sessions. Three skills are emphasized: (a) choosing safe crossing routes, (b) crossing safely between parked cars, and (c) crossing safely at intersections. Initial data suggest that recruitment of volunteer teachers can be completed easily and that Kerbcraft increases children’s pedestrian safety in all three targeted domains.[119]

Conclusions

Although adults act quite automatically, crossing the street safely is a complex cognitive, perceptual, and motor task that requires children to have developed multiple advanced skills. As reviewed, a growing literature outlines the cognitive, perceptual, and motor tasks required by a safe pedestrian, and the ages at which those individual skills typically develop. Nonetheless, a complete understanding of the multiple developmental aspects of safe

pedestrian behavior, and how those skills might be implemented simultaneously and/or sequentially by the child pedestrian, remains lacking in the literature.

At the same time scientists work to develop a more complete understanding of the developmental aspects of safe pedestrian behavior, behavior-oriented pedestrian injury prevention efforts continue. A range of parent, school-based, technology-based, and community efforts have been attempted, some with excellent success. Multifaceted approaches, including approaches that incorporate vehicle, road, and traffic engineering, may be most effective.

What can individual professionals and parents do to reduce pediatric pedestrian injury risk? We offer a few recommendations. First, they must consider the child's development. Young children simply cannot cross streets safely, and should not be permitted to do so. By age 7 or 8, and certainly by age 9 or 10, many children can learn to cross streets safely. To achieve safe pedestrian skills, however, and for adults to feel comfortable allowing children to cross independently, adults must conduct extensive practice, review, and evaluation. Such training ideally would come from multiple sources –parents, teachers/schools, and other professionals in the community. Beyond education, parents and professionals should advocate for safer pedestrian environments. Strategies such as road engineering (e.g., traffic calming; building foot-bridges), use of crossing guards near schools, and community organization of pedestrian safety initiatives should be promoted. Finally, professionals should encourage awareness. Pedestrian injury is the third-leading cause of injury-related death among elementary and middle schoolers in the United States;[3] we should encourage public awareness, public spending, and public infrastructure to be commensurate with the scope of the public health problem.

As is the case for most domains of public health, we have made substantial progress addressing the burden of pediatric pedestrian injury over the past several decades. But much work remains to be done. Basic and applied research must continue to explain better the processes required for children to negotiate street environments safely. Empirically-supported and theoretically-driven prevention efforts must be developed to improve existing options, and must be honed and then demonstrated effective via scientifically-sound experimental trials. With the cooperation and collaboration of multiple stakeholders, we will continue to alleviate the public health burden of child pedestrian injuries.

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