Role of Environmental Interventions in Injury Control and Prevention

Corinne Peek-Asa and Craig Zwerling

From the University of Iowa Injury Prevention Research Center, Iowa City, IA.

Received for publication August 29, 2002; accepted for publication February 3, 2003.

Abbreviation: CPTED, Crime Prevention Through Environmental Design.

CAUSAL MODEL OF INJURIES

Injuries result from transfer of energy to a human host. In the epidemiologic model of infectious disease, microbes are the “agents” of infection. Similarly, in the epidemiologic model of traumatic injury, energy is the “agent” of injury (figure 1). This model provides a good basis for understanding the role of the environment in the causal pathway for injuries.

Transfer of energy to the host is the final step in the causal pathway for injuries, but many factors influence the nature of this exchange and its consequences. Energy that causes injuries can be in several forms, including kinetic, chemical, or thermal. For example, kinetic energy causes motor-vehicle-related injuries, and thermal energy causes burns. Lack of metabolic energy that occurs through external forces, such as during drowning or suffocation, can also be included in the definition of injuries. Energy can be transferred to a human host through vehicles (inanimate objects such as motor vehicles) or vectors (animate objects such as another human). Some injuries require both a vehicle and a vector, such as a gunshot wound that requires a firearm and ammunition (vehicles) and someone to shoot it (vector).

The potential for energy transfer exists just about everywhere, but certain environmental characteristics increase the potential for injury. If these characteristics can be understood, we may be able to modify the environment to remove or reduce energy transfer. Since humans have designed and constructed most of our environments, it is a logical but often forgotten premise that we can modify this environment to be safer.

The environment is a complex interaction of physical, social, economic, cultural, and demographic features. In this article, we focus primarily on the physical environment. Other articles in this volume of Epidemiologic Reviews address social, economic, and cultural components of the environment. Injury prevention strategies aimed at changing the physical environment are among the most successful injury control interventions. However, successful interventions must always consider the entire causal pathway; thus, the best approaches are multifaceted. This article describes some of the reasons for the success of environmental approaches and provides some examples that describe the many ways that the environment can be modified. We have concentrated on the epidemiologic and public health literature, but further evidence can be found in the engineering, policy, economic, and legal literature. Many more environmental approaches have been implemented than have been evaluated, and we also identify some promising areas of future impact. This article also discusses the difficulty in conducting research evaluations of environmental modifications.

CLASSIFICATION OF THE PHYSICAL ENVIRONMENT

The physical environment, and changes within the environment, can be categorized as natural or man-made. For
example, weather-related injuries, such as those associated with tornadoes, floods, and extreme temperatures, are related to global climate trends, which are part of the natural environment. The roadway and buildings are examples of the man-made environment.

Although our ability to manipulate the natural environment may be limited, understanding the relation between the natural environment and injury risk may suggest important avenues for intervention. Often, the man-made environment can be modified to reduce injury risks inherent in the natural environment. For example, persons in mobile homes are at extremely high risk of injury during tornadoes, yet mobile homes are often found in areas frequently affected by tornadoes (1, 2). Tornado-related deaths and injuries can thus be reduced through interventions focusing on the natural environment, such as careful urban planning and land use policies that consider environmental risks, and those focusing on the man-made environment, such as improving the structures built in tornado-prone areas. However, interventions that incorporate land use policies are rare in disaster planning.

Changes in the physical environment related to the risk of injury can be intentional or unintentional. Many examples of intentional modifications implemented to reduce injuries are described in this article and include changes to roadways, businesses, and residences. Unintended changes in the environment can lead to increased or reduced injury risk. The increasing number of sport utility vehicles on the roadway may lead to increased injury severity and fatality rates because larger cars cause more damage when crashing with smaller cars (3, 4). In contrast, several elements of the socio-economic and demographic environment contributed to reduced violent crime rates in the late 1990s. These elements include a smaller proportion of the population between the ages of 15 and 39 years, a group that tends to have the highest criminal perpetration rates, and a strong economy.

**HISTORY OF THE PUBLIC HEALTH APPROACH TO ENVIRONMENTAL INTERVENTION**

Dr. Hugh De Haven first recognized the potential to modify the environment to prevent injury (5). His early research in the 1940s examined the causal pathway for injuries from falls and from airplane crashes (6, 7). He identified the thresholds of injury based on the height of the fall and also recognized that the configuration of an airplane cockpit influences the potential for injury in a crash. Researchers such as Drs. John Stapp and William Haddon measured the human body’s tolerance for brief exchanges of mechanical energy, such as that sustained in a motor vehicle crash, and found that the physical environment can be modified to greatly enhance the survivability of a crash (8).

Before this groundbreaking work, injury control research had focused on identifying behavioral risk factors associated with the host (5, 9). Therefore, the responsibility for injury prevention rested largely on the individual person. Dr. Haddon argued that no matter how resilient the human host becomes, both physically and through education, he or she will not be able to overcome injury risks inherent in the environment. However, modifying the environment requires not only an understanding of how the environment can be changed to reduce injury risk but also action by decision makers, such as government officials, who can initiate large-scale change. Efforts to modify the environment are thus multifaceted and often expensive.

Although sometimes difficult and expensive to implement, environmental modifications have been among the most effective approaches to preventing injuries, for two reasons. First, environmental modifications are usually passive to the persons in the environment (10, 11). A passive intervention does not require specific activity by the host for the intervention to work. For example, an air bag is passive; once it is installed in the car, the driver does not need to activate it to be protected while driving. In contrast, a seat belt is an active intervention because the driver must buckle it to receive its protective effects.

Second, environmental modifications often protect many persons. Although changes in the environment may be difficult to implement, all those who interact with the changed environment will benefit from the injury-reducing modifications. For example, changes in roadways, described in more detail later in this article, protect all drivers.

As introduced by Dr. Haddon (5, 10) and discussed by Runyan in this volume (12), the Haddon Matrix divides injuries into three phases: pre-event, event, and post-event. The following sections provide examples of environmental interventions to reduce injuries in each of these phases.

**ENVIRONMENTAL STRATEGIES TO REDUCE INJURIES IN THE PRE-EVENT PHASE**

Interventions in the pre-event phase aim to prevent transfer of energy to the host. Such primary prevention interventions can often be very effective because they protect the host from energy exposure. They do not depend on host resilience or other factors that can increase the potential for injury given an energy transfer. Environmental strategies in the pre-event phase are the most promising of injury prevention approaches.

**Modification of the roadway environment**

The number of motor vehicle miles (1 mile = 1.61 km) traveled in the United States increased from approximately 206 billion in 1930 to over 2,467 billion in 1996 (13) (figure 2). In addition to this increase in exposure, factors such as increased congestion on roadways, increasing numbers of licensed teenaged drivers, increased alcohol consumption, increased speed capabilities of cars, and generally increased speed limits would all seem to predict an increase in the rate of motor-vehicle-related deaths per million miles traveled (14).

However, the fatality rate per 100 million vehicle miles traveled decreased from 16.0 in 1930 to 1.5 in 2000 (figure 2) (13). The National Highway Traffic Safety Administration and the US Federal Highway Administration estimated that between 1966 and 1990, 243,000 lives were saved as a result of highway, traffic, and motor vehicle safety programs (13). Although many factors contributed to the decline in motor-vehicle-related fatality rates, one major factor has been changes in the roadway environment.
With increased urbanization and reliance on cars came a shift from two-lane rural roads to interstate freeways. Although vehicle volume and speed are highest on interstate states, the number of crashes per mile traveled is the lowest for all types of roadways. This lower crash rate is largely due to road modifications mandated by the Federal Highway Safety Act of 1966, implemented after growing concern over traffic fatalities (14).

Safety features built into interstate roads are numerous. Divided highways separate traffic flow in different directions, avoiding lane crossings and reducing the risk of head-on crashes. Curves are graded to reduce the risk of cars running off the road. Skid-resistant surfaces have been developed to reduce loss of traction while braking. Lighted signage has been added to increase visibility and reduce distraction. On- and off-ramps help control the integration of slow-speed with high-speed traffic. The top half of figure 3 shows a rural roadway that has not incorporated environmental safety features, whereas the bottom half of figure 3 shows an interstate roadway that has been modified with the roadway improvements described above. These roadway modifications are so effective because they protect all road users, regardless of their level of training, risk-taking behavior, experience, or other risk-related behaviors.

**Modifications to reduce violence in the workplace**

Homicide is the second leading cause of traumatic death in the workplace, following transportation-related deaths (15). Approximately 40 percent of all workplace homicides occur in the retail industry, and these events decreased 46 percent between 1994 and 1999 (15). The majority of workplace homicides are robbery related (16).

The environmentally based approach called Crime Prevention Through Environmental Design (CPTED) originated in the 1970s to reduce robberies and associated violence. CPTED aims to modify the work environment to reduce vulnerability to crime, allowing businesses direct control of the environment rather than relying on indirect control of criminal behavior (17, 18). If robberies can be prevented, then the injuries and deaths that occur during robberies will also be prevented.

The CPTED model identifies four elements for environmental modification: natural surveillance, access control, territoriality, and activity support. Natural surveillance includes internal and external lighting—and visibility into the store—and placement of the cash register. Access control includes such factors as number of entrances, door type and placement, and design of the internal environment to control customer movement. Territoriality addresses the location of the store within the community, traffic flow surrounding the store, signs and advertisements for the store, and design issues that empower the employees over the customers (such as bulletproof barriers). Activity support includes efforts to increase the presence of legitimate customers and encourages both increased business and good customer behavior.

Figure 4 depicts one store environment that does not follow CPTED principles (top), which is in contrast to a store environment that does (bottom).

Published evaluations of the CPTED approach indicate that it is successful in reducing robberies (19). Robberies of businesses that introduced the CPTED approach decreased 30–84 percent compared with control stores (19–21). In addition, four studies evaluated a series of Florida ordinances that required security measures such as limited cash in registers, increased lighting and visibility, staffing and hour changes, and employee training (22–25). These ordinances led to robbery decreases of 12–65 percent, with only one study not observing a significant decrease. Evaluations of the CPTED approach that examined injury and homicide as an outcome generally found decreases in assaultive injury to employees but did not find decreases in homicides (19, 26). The two studies examining homicides had insufficient power and did not control for background crime rates; thus, these findings are not conclusive (19). Other positive outcomes included reductions in monetary losses and increases in perpetrator apprehension (19).

Although the evidence consistently shows success of this approach, the methodological approaches used in the evaluations are weak. Most studies involved pre- and postintervention comparisons without a control group, and many had small sample sizes (19). Perhaps the most serious methodological concern is that most studies did not measure compliance with the program, so a direct connection to implementing the program cannot be made.

The CPTED approach can be applied in many settings, including hospitals, schools, and even residences (19). However, the effectiveness of this approach has not been evaluated outside of the retail industry. Research also suggests that the CPTED model might be more effective if integrated with administrative and behavioral approaches. One recent case-control study found that among a series of environmental characteristics examined, only access control and lighting were effective in reducing the risk of all types of workplace homicide (27). However, combinations of administrative approaches, which included reducing exposure during late night hours, did lead to a reduced homicide risk.
FIGURE 3. Examples of rural and interstate roadways, United States. Top: a rural road with no divided lanes, nongraded curves, and no shoulders. Rural roads have the highest per-mile crash rate (1 mile = 1.61 km). Bottom: an interstate with divided lanes, controlled entrances and exits, good signage, graded curves, and shoulders. Although cars travel at higher speeds on interstates than on other road types, interstates have the lowest per-mile crash rate.
Modifications to protect the child pedestrian

Each year in the United States, approximately 850 children under the age of 15 years are killed and another 30,000 injured in pedestrian collisions (28). Children less than age 15 years represented 23 percent of the population but 30 percent of the nonfatal pedestrian injuries and 11 percent of the pedestrian fatalities in 1998 (refer to the following Internet Web site: www.cdc.gov/ncipc/factsheets/pedes.htm).

Most educational programs that train children to cross streets have demonstrated limited success in reducing pedestrian injury (29). The main reason suggested for these results is that children, especially young children, are not cognitively ready to handle the complex traffic environment. Challenges for children include difficulty seeing and processing traffic patterns, judging speed of vehicles, prioritizing street-crossing activities, and choosing an adequate gap in traffic to cross the road (28, 30, 31). Changing children’s behavior is difficult.

However, many environmental risk factors for pedestrian injuries have been documented, including high traffic volume, a large number of parked cars, multiple lanes of traffic, higher speed limits, decreased visibility, and poor maintenance of street signage (29, 32–35). Population-based environmental risks include a high population density, household crowding, lack of play areas, and a large proportion of multiple-family dwellings (29, 32–34). Existing studies show that children are often hit by cars when they dart out into the street (36) and that toddlers are often hit in driveways (34).

These findings suggest that environmental approaches that separate children from the traffic environment and slow traffic in places where children might be in the street would be effective. For example, using fences to physically separate children from driveways was associated with a threefold decrease in driveway-related child pedestrian injuries in New Zealand (37). However, some approaches to accomplish this goal have been controversial. Marked crosswalks, although designed to protect pedestrians, have been shown to actually increase the risk of pedestrian injury and may present a false sense of security (29, 33, 35).

One approach that has garnered increasing international attention is “traffic calming.” The tenet of traffic calming is that each environment presents specific risks for road users, and these risks should be identified and addressed locally. Implementing traffic calming measures begins by identifying the nature and extent of local traffic problems and then using a “toolbox” of mostly physical measures to address the specific problems (38). These tools include traffic circles and roundabouts, speed humps, chicanes, modifications of street width, barriers, street closures, as well as many others (38). Figure 5 depicts a three-way intersection in which a traffic roundabout was introduced to control traffic flow.

Preston (39) reviewed 19 evaluations of traffic-calming interventions and found that injury reductions ranged from 14 percent to 85 percent. Elvik (40) conducted a meta-analysis of 33 traffic-calming evaluations and found that injuries decreased an average of 15 percent overall and 25 percent on residential roads. Because of the wide variation in traffic speed, traffic volume, and roadway design of communities, each circumstance must be reviewed independently before choosing the best combination of approaches. Recognition of this variation keeps traffic calming from being a “one size fits all” approach and may be one reason behind its success.

Home modifications to reduce falls in the elderly

Falls are a significant health concern for the elderly because of their frequency and the potential for serious consequences. Falls account for approximately 25 percent of injury deaths among those over age 65 years, and 34 percent of injury deaths among those aged 85 years or older, usually as a result of complications from hip fractures (41). Falls are
also a major cause of disability and loss of independence in the elderly (42, 43). Twenty-five percent of the elderly who sustain hip fractures die within 6 months of the injury, and more than 50 percent of community-dwelling older adults who survive hip fractures are discharged to nursing homes and require rehabilitation for more than a year (44).

The home environment has been identified as a potential contributor to as many as 50 percent of falls occurring to the elderly (45–49). Furthermore, research indicates that the majority of homes in which the elderly live have at least one, and usually more, environmental hazard (50–52). These hazards include obstructed pathways, loose throw rugs, poorly

FIGURE 5. Use of traffic-calming measures to reduce traffic-flow problems in Coralville, Iowa. Top: three-way intersection before traffic calming, where cars at one intersection were backed up because of an uneven traffic flow. Bottom: the same intersection with a roundabout that evens traffic flow, is scenic, and controls speed. Courtesy of Scott Larson, Assistant City Engineer, City of Coralville.
maintained stairways, poor lighting and visibility, hard surfaces on which to fall, and lack of safety devices such as grab bars. As residents age, problems with vision, balance, chronic conditions, and side effects of medication may hinder their ability to negotiate these home hazards. Thus, the causal pathway for falls often involves the interaction of predisposing factors with precipitating factors in a person’s environment (53).

These risk factors suggest that modifying the home environment would be a successful approach to reducing falls and related consequences. However, research identifying specific household risk factors and falls is inconsistent. Some research successfully links home hazards with fall incidence (45, 47, 49), but the specific hazards that are meditated are not consistent among studies. Other research shows no association between specific risk factors and falls (48). This research does illustrate that falls are often the result of multiple factors, and it is difficult to identify which of these factors are most successfully amenable to intervention.

Since the relation between specific home hazards and fall risk is not completely clear, it is no surprise that evaluations of interventions to modify the home environment are also inconsistent. In two randomized controlled trials that examined home modification in the absence of other approaches, Cummings et al. (54) found an overall decrease in fall risk, especially among those with a history of falling, when modifications such as nonslip bath mats, lighting at night, and stair rails were recommended by an occupational therapist. However, Stevens et al. (55) found no decrease in falls compared with a control group. Gillespie et al. (56) conducted a Cochrane Library review of randomized controlled trials of interventions to prevent falls in the elderly. They concluded that home modification in the absence of other intervention approaches may be effective for persons with a history of falling but is likely to be most effective when integrated into a multifaceted intervention program that also focuses on medications, exercise, and nutritional status. This conclusion was supported by Day et al. (57), who evaluated group-based exercise, home hazard management, and vision improvement in reducing falls among over 1,000 independently living elderly. The group that received all three interventions experienced a 14 percent reduction in the annual fall rate, which far surpassed the rate for any of the interventions individually.

ENVIRONMENTAL STRATEGIES TO REDUCE INJURIES IN THE EVENT PHASE

In the event phase, prevention aims to reduce the amount of energy transferred to the host when an energy-producing event is present, thereby reducing the severity of injury or eliminating injury altogether. Although energy transfers causing injury often occur in milliseconds, effective environmental approaches have been developed to reduce the amount of energy transferred to the host once an injury risk factor is present.

Home modifications to reduce fire-related deaths and injuries

Fires and burns are the seventh leading cause of injury death in the United States (41). In 2001, exclusive of the terrorist attacks of September 11, 2001, residential fires comprised only 23 percent of reported fires annually but were responsible for 83 percent of the civilian deaths, 77 percent of the civilian injuries, and 53 percent of the property loss associated with fires (58). Fire kills across the lifespan; the rates for children aged less than 5 years and adults aged more than 64 years are two to six times higher than those for other age groups (59).

The home environment can be modified in many ways to reduce injuries and deaths from fires. Modifications include installing smoke alarms and sprinkler systems, fire extinguishers, and devices such as rope ladders to enable escape from a burning residence. Of these measures, the smoke alarm has been the most frequent subject of research.

In North Carolina, Runyan et al. (60) estimated that residents of homes without a smoke alarm have 3.4 times (95 percent confidence interval: 2.1, 5.6) the risk of fire death as residents of homes with a smoke alarm. Hall (61) reported that smoke detectors cut the risk of dying in a home fire by about 40 percent in the United States, with 0.57 deaths per 100 home fires with alarms compared with 1.03 deaths per 100 home fires without alarms. The National Fire Protection Association estimated that 75–80 percent of the fires that would have grown large enough to be reported in the absence of alarms are not reported when alarms are present because people do not need fire department aid (61).

Although evidence suggests that smoke alarms are highly effective, their use is not universal even after nearly three decades of availability. This is an excellent example of how behavioral or regulatory approaches are sometimes necessary to require the use of existing interventions that change the physical environment. Although approximately 88 percent of homes have at least one installed smoke alarm, the alarms are not functional in about one quarter to one third of them (62–64). Even fewer homes meet the National Fire Protection Association code requirement of at least one working alarm per floor and near each sleeping area (61). In a survey conducted by the Consumer Product Safety Commission, 55 percent of nonfunctioning alarms did not have batteries, 25 percent had dead batteries, and 15 percent had disconnected batteries (62).

Two recent systematic reviews of interventions to promote smoke alarms (65, 66) found few published controlled evaluations of alarm promotion programs, and most of these evaluated educational approaches to increase use. DiGuiseppi and Higgins (65) pooled results from 10 randomized trials on smoke alarm ownership and concluded that educational programs to promote smoke alarm installation and maintenance had only modest effects on increasing smoke alarm ownership or functionality. Educational programs in clinical settings and those that combined education with discounted alarms showed slightly higher gains in ownership and function. Warda et al. (66) reviewed 10 interventions that aimed to increase smoke alarm use and function, some that overlapped with the studies that DiGuiseppi and Higgins evaluated, and again concluded that educational programs had a modest, if any, effect.

Studies that evaluated the incidence of fires and fire-related injuries following smoke alarm giveaway programs have had inconsistent results. Three studies found decreases
Few evaluations of other environmental approaches to reduce fire-related deaths exist. On the basis of evidence in industrial settings from the Federal Emergency Management Agency, the Council on Scientific Affairs of the American Medical Association recommended widespread installation of residential sprinkler systems (70). However, the role of these systems in dousing fires and saving lives has not been documented. Although sprinklers would require very little maintenance, the ability of owners to change sprinkler heads is not known and, as suggested by the lack of maintenance of smoke alarms, may be poor. Although the cost of installing, and even more so retrofitting, sprinklers is high, better technology is reducing these costs.

ENVIRONMENTAL STRATEGIES TO REDUCE INJURIES IN THE POST-EVENT PHASE

Post-event intervention aims to reduce the consequences of an injury-producing event after energy transfer has occurred. This goal can be accomplished by reducing the time between injury and medical treatment, improving medical treatment, implementing effective rehabilitation to reduce physical impairment and disability, or providing services, such as mental health services, to reduce trauma following the event.

Environmental modifications that affect the post-event period are usually implemented before the event, but they act after the injury to reduce negative sequelae. Post-event environmental modifications are often part of a cycle in which knowledge gained from an event can be applied to reduce consequences of a similar event in the future. This cycle requires that post-event consequences be examined and that knowledge from this examination be applied during the next event. Therefore, many post-event environmental modifications involve a complex interaction between the physical and socioeconomic environments.

Modifications to the delivery of emergency and trauma care

Improvements in emergency medical response and trauma care have had a major impact in the field of injury control. Identifying the relation between time to definitive treatment following an injury and the outcome of that injury has led to development of coordinated trauma care from the prehospital through the rehabilitative phases (13). Implementation of trauma systems has mainly involved changes in the social environment, which have included better coordination between agencies, triage and transport protocols, assignment of treatment levels to trauma centers, and improved training and certification at all levels of emergency care delivery.

Early evaluations of trauma systems focused on the number of deaths that could be prevented, and estimates were in the range of 20–40 percent (13, 71, 72). These studies had many methodological flaws including lack of appropriate comparison groups, failure to control for confounding, and small samples without identification of a base population (73). However, studies adopting better methodologies and using population-based approaches have also reported significant reductions in fatalities (74, 75). These findings have led an increasing number of US states to implement coordinated trauma systems, yet there are still important gaps in knowledge regarding the effectiveness of trauma systems, especially with regard to prehospital care and long-term outcomes (13). These knowledge gaps were most recently reviewed in the Journal of Trauma (1999, volume 47) and are not discussed in detail here.

Coordinated trauma care has also led to changes in the physical environment that have contributed to increased survival and recovery from an injury. The major goal of these changes is to reduce the time between an injury and definitive medical care, and they include an increase in the number and quality of emergency medical vehicles, improved emergency communication systems (such as “911” telephone response), and improved medical equipment for treating trauma. Few evaluations of these changes to the physical environment have been published in the medical literature. One evaluation of the 911 emergency telephone number found that incorporating the single-use three-digit number was a more efficient and successful way to activate the emergency medical system than the previous multiple seven-digit numbers (76).

The use of helicopters to transport critically ill patients is one example of an intervention in the physical environment. Many communities use helicopters to reduce transportation time, especially in rural areas or areas that present challenges to ground transportation, such as dense urban freeways. Because helicopter crews often include highly trained medical personnel, their use also brings critical care to the patient in the field. Evaluations of helicopter use have had mixed results. While some studies have found improved survival with helicopter transport (77–82), others have reported no benefit (83–85) and some have found that the benefits are limited to a very small proportion of patients transported in the helicopter (86, 87). Studies in rural settings tended to find more favorable outcomes, and studies that did find an effect often attributed it to the presence of medical personnel on the flight crew rather than a decrease in transport time (80, 81). Studies evaluating helicopter use are difficult to compare because they apply different criteria for determining appropriate use and identification of survival potential, use different control groups (and often no control groups), and use different types of transport, including on-scene-to-hospital and hospital-to-hospital.

The environment and disaster response

The area of disaster response provides a good example of how the environment is related to the post-event phase. Natural disasters throughout the world have caused an average of 3 million deaths each year for the past 20 years, and many more injuries (88). Natural disasters that require international assistance occur almost every week. Man-made disasters, such as industrial incidents, refugee crises, and terrorism add to this toll. Because of increasing population densities, development and transportation of toxic and hazardous materials, and increasing globalization, the death rate from disasters will likely grow in the future (88–90).
Following a disaster, emergency responders must be able to quickly initiate search and rescue activities, provide medical care, and provide food and shelter to affected populations (90). Disaster response is influenced by both the natural and man-made environments. Weather-related events such as tornadoes, hurricanes, and extreme temperatures hinder the ability of rescue teams to access injured persons. Hurricanes, earthquakes, and erupting volcanoes can lead to secondary natural phenomena such as floods and landslides, and these events also hinder rescue efforts. In addition to hindering rescue efforts, unfavorable elements in the natural environment can reduce the ability of response agencies to provide clean water, food, and shelter to disaster survivors (91). Improvements in search and rescue equipment and technology have helped overcome these problems, but many developing countries, which tend to be disproportionately impacted by disasters, do not have access to these advances.

The man-made environment is also related to post-event recovery. For example, building integrity is an important component in earthquake response. Buildings that collapse cause increased death and injury and are more difficult to negotiate during search and rescue activities. Collapsed buildings are also much more difficult to reconstruct following a disaster. Engineering research has clearly documented that wood-framed buildings are less likely to collapse during an earthquake (92). Buildings with heavy roofs and less-stable walls, such as mud houses with adobe roofs that are found throughout the developing world, are extremely susceptible to collapse. The United States and Japan have both implemented sophisticated seismically sound buildings in earthquake-prone areas, but, again, developing countries rarely have the resources to do so.

The man-made environment includes all of the necessary communication and transportation infrastructures necessary to respond to a disaster. The New York Times reported widespread radio and communications failures with firefighter’s equipment during the response to the terrorist attacks on September 11, 2001 (93). Because of these malfunctions, many firefighters did not hear orders to evacuate the second World Trade Center tower, leading to many preventable deaths. Failed bridges, roadways, traffic control systems, and energy sources are routinely identified as hindrances to emergency response (90, 91). Thus, infrastructure planning is a promising area for environmental intervention in disaster response.

UNINTENDED CONSEQUENCES OF ENVIRONMENTAL CHANGE

Changes in the environment, whether intentional or unintentional, can lead to increased injury risk. Sometimes this risk can be due to unintended consequences of an environmental change implemented to reduce injury risk.

One example of this phenomenon is the air bag. As with most of the modifications to the vehicle interior, design specifications were based on the size of the average male (94). An increasing number of air-bag-related injuries to children and small adults brought attention to air bag design beginning in the early 1990s (95). The first cases indicated that the problem was largely associated with unrestrained children or infants seated improperly in the front seat while in rear-facing infant seats (96). However, further research indicated that older children adequately restrained in the front seat were still at high risk of fatality from air-bag-induced injuries, even in low-speed collisions (97). Analysis of several years of data indicates that children under the age of 10 years who are in the right front passenger seat have a 21 percent increased risk of fatality when an air bag is present (98).

Since then, federal agencies, including the National Transportation Safety Board and the National Highway Traffic Safety Administration, have recommended that infant car seats and children under age 12 years always be placed in the back seat in cars equipped with passenger-side air bags (99). Many agencies have supported broad public campaigns to promote this message. In addition, engineers are working to improve the air bag to reduce these unintended consequences. Current technology includes the “smart” air bag, which deploys in response to the passenger’s height and weight (100, 101). Note that, although the air bag poses a real injury risk to children who are inappropriately seated in front, many more children are killed each year because they are not adequately restrained.

The environment can also change in predictable ways that unintentionally lead to injury risk. Vulnerability to disasters is one example. In the United States, deaths, injuries, and financial losses from disasters have increased dramatically over the last several decades (90). However, the frequency of large-scale disasters has not increased.

One reason for the increased vulnerability involves population shifts to vulnerable areas. Currently, 80 percent of the Florida population lives within 35 km of the coastline, and these areas are highly vulnerable to hurricanes (90). Another example is California, which saw its population grow from 10 million in 1950 to 33 million in 1990 and become increasingly concentrated in metropolitan areas (90). Most of this population is at risk of earthquakes. Although population shifts do not change the natural environment, they lead to changes in the built environment in these areas. In addition to the increased number of persons at risk, the environment shifts toward larger buildings, increased population density, and increasingly complex transportation, communication, and service infrastructures.

The environment is also sometimes modified intentionally in ways that increase injury risk. One example is the end of the required 55 mile-per-hour speed limit. This speed limit was imposed not to reduce injuries but to increase fuel efficiency during the petroleum crisis (4). The federal speed limit requirement on rural interstates was increased to 65 miles per hour in 1987; in response, many states and municipalities increased their speed limits. Although evidence is conflicting, most indicates that higher speed limits led to increased crashes and associated deaths and injuries (4, 102, 103).

EPIDEMIOLOGIC STUDIES OF THE ENVIRONMENT

The epidemiologic literature evaluating environmental interventions is very scant compared with the variety of interventions implemented. With notable exceptions, most
evaluations of environmental interventions use weak, often quasi-experimental designs, often without a control group, and underuse analytic techniques. Many factors have contributed to the lack of stronger research designs. Inadequate funding has prohibited use of randomized controlled trials and prospective studies in many settings. In addition, randomized designs are often infeasible or unethical to implement when interventions focus on environmental change. Many of the evaluations were conducted prior to the widespread use of personal computers, and advanced, straightforward statistical software was not available. Finally, the multidisciplinary nature of the field of injury control has led to a literature spread across many fields; each uses its own approach to research. Comparing findings in this broad field is difficult.

Considering these hindrances to research, it is not surprising that many of the existing evaluations use ecologic study designs and rely on retrospective, secondary data. In addition, many of the analytic approaches include only a pre- to postintervention comparison with no control group, and they often fail to control for known confounding factors. The early evaluations of roadway changes are predominantly ecologic, and it is difficult to draw causal connections from them. These studies often do not control for heterogeneity of the regions being studied (such as variance in baseline fatality rates in different states) or attempt to control for simultaneous interventions that might influence injury rates. A large body of economic research has evaluated roadway and motor vehicle safety features, but this research fails to consider many of the confounding factors that affect both crash incidence and injury severity (4).

Several randomized controlled studies have been conducted in the home setting, but many have insufficient power to detect differences. Existing literature suggests that home modification may be effective as part of a multifaceted intervention approach, but very large sample sizes are required to detect the role of individual components of an intervention program.

Despite these weaknesses, some very promising approaches exist. A larger funding base will increase opportunities to conduct randomized controlled trials, and they will offer the best assessments of effectiveness. Certain study designs are also well suited to study the environment. One example is the “case-site, control-site” study design, a variant of the traditional case-control approach. This design has been used widely in studying pedestrian injuries (29, 33, 104). The “case” in this study design is a child pedestrian collision, and characteristics of both the child and the location are incorporated. Controls are chosen from locations where children were not hit, and they are usually selected through a stratified random sampling scheme that controls for environmental factors not under investigation. This design is especially useful for environmental research.

The case-crossover design is also a promising approach to studying the environment. In this design, cases serve as their own controls, and thus many confounding factors will be inherently matched (105). This design is especially helpful when many confounders are unknown, often the case with environmental influences. One example of the case-crossover design examined cellular telephone use and driving crash risk (106). In this study, cases were 699 drivers with cellular phones who were in crashes causing substantial property damage. Phone records for the day of the crash were compared with those from a week prior to the crash. Therefore, subjects served as their own controls during a time period prior to the outcome event. Investigators found a fourfold increase in crash risk when the phone was being used.

Stronger analytic strategies are also underused in some environmental studies. Use of interrupted time-series modeling is rare, even when prolonged baseline and follow-up data are available. Time-series analyses may be particularly important in environmental evaluations because ecologic study designs are so often used, and interrupted time-series models are one of the best approaches to control for confounding effects by using ecologic data (107). This design would have been particularly helpful for the series of evaluations of Florida ordinances to reduce robberies and related injury. These studies used ecologic study designs to compare the rate of robberies and homicides before and after implementing the ordinances (22–24). However, they did not control for expected changes in violent crime, which were generally decreasing during the study period. Thus, the effects of the program could be overestimated, and this bias could have been controlled by using an interrupted time-series design.

Hierarchic modeling is a promising strategy to control for clustering of events. By introducing a random-effects term into the intercept of a model, units in which events cluster can be controlled and examined (105). This approach would be appropriate for studies comparing crash rates by state because states, each with their own laws and enforcement strategies, have different factors predicting crash rates. This approach would also be helpful in studies evaluating robbery-prevention programs because individual stores have different risk factors for robbery.

Evaluation research on environmental modifications has improved greatly since the early ecologic studies of the roadway to the randomized controlled trials of fall prevention programs in the home. There is great promise for the future, and better evaluations of environmental approaches will help guide decisions about the use of scarce prevention resources.

CONCLUSION

The injury prevention examples described in this article demonstrate that modifying the environment may require large-scale change involving many stakeholders. Bringing together all of the stakeholders around an environmental intervention will usually require integration with behavioral and regulatory interventions.

For example, successful modification of the roadway and vehicle environments required collaboration of legislators, urban planners, city councils, law enforcement, automobile manufacturers, engineers, and health professionals, among others. Prevention efforts focusing on the seat belt required engineering, education, and legislative approaches. Legislation was required first to get seat belts installed in cars and then to get drivers and passengers to wear them. Doing so
required education of legislators to understand the scope of the problem and the promise of reducing it. Thus, it can be argued that environmental change does not occur without some underlying change in knowledge, attitudes, culture, or beliefs in the persons or groups that can institute environmental changes.

The causal pathway of most injuries is complex. Preventing injury events and reducing the severity of injuries requires coordinated effort and multifaceted approaches. Changing the environment remains one of the most promising approaches to reducing injuries, but environmental approaches will be effective only if they are designed and implemented with a full understanding of the complex and changing nature of the environment. This understanding will depend on increased funding of robust evaluative research.

ACKNOWLEDGMENTS

Support was provided by the University of Iowa Injury Prevention Research Center (CDC CCR 703640).

The authors thank Dr. Nancy Sprince for reviewing the manuscript.

REFERENCES