Injury Epidemiology: Fourth Edition

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Lulu Books
Revised 2022

Chapter 10. HUMAN FACTORS

Most people who are injured are doing something at the time -- driving, riding in a vehicle, ingesting food or drugs, walking, working, or playing. So are people who are infected by microorganisms, but those who study injury place more emphasis on behavior than those who study most infectious diseases. Notable exceptions in the past are infectious diseases transmitted by sex. Ironically, sexual behavior in moving vehicles has been neglected as a topic for research. In earlier editions of this book, I noted no relevant studies were found in a search on Google Scholar regarding sexual behavior and vehicle crashes. One study based on media reports was published more recently (Oviedo-Trespalacios and Phillips, 2021). While the relative risk is not calculable from such sources, the distraction likely contributed to the crashes. With the onset of the Ebola and COVID-19 epidemics, behavioral factors that increase exposure to viruses transmitted person-to-person gained greater attention but people's behavior after receiving negative tests was ignored (Robertson, 2022).

Historically manufacturers of injurious products or products that could be changed to reduce injury severity emphasized behavior as the cause of injury to divert attention from the products (Eastman, 1984). Despite the claims of industry spin-doctors and their apologists in government, injury control has never been a simple choice of changing agents and vehicles of injury versus changing behavior. The issue is: what factors can be changed to reduce harm and how much injury reduction can be achieved by deliberate attempts at changing the factors? Certainly, not all injuries are preventable by modifying energy conveyances or modification of environments and behavioral change can be accomplished to some extent. To do so will require a better scientific understanding of the behaviors involved, whether they can be modified and how to do so on a large scale.

BEHAVIORAL THEORIES. The construction of behavior change strategies would be easier if behavioral and social scientists could agree on human behaviors that are changeable. For example, historical arguments regarding the best approaches to crime prevention turned on the issue of the extent to which behavior is modifiable at what stages of development (Tremblay and Craig, 1995).

The operant conditioning model prevalent among experimental psychologists portrays human beings as trainable by reward and punishment to do virtually anything and often ignores biological limitations such as reaction time, as well as cognitions that intervene between the input of rewards and punishments and the output in behavior. The neoclassic economic model, and that of some cognitive psychologists, views human beings as rational "utility" (goal) optimizers. There is also little room for human physical or psychological limitations in this model (low intelligence, mental illness, and addictions, for example). Rather than being mainly responsive to external stimuli as in the operant conditioning model, the rationalists think that each person weighs each option for behavior as to its probability for accomplishing or experiencing a utility, and discounts the cost in terms of the time between the immediate situation and the ultimate goal. The origin of the "utilities" is often obscure in such theories.

Many sociologists view behavior as largely influenced by the internalized cultural and social environment, including learned social customs and mores, socioeconomic status, and peer pressure. Socio- and psycho-biologists emphasize the effects of genetics on the biological factors that contribute to motivations such as rivalry, emotions such as rage, cognitive limitations, and neuronal-motor function. Certain psychologists and psychiatrists look for the major motivations for behavior in the unconscious mind, they think largely determined by relationships with parents or guardians in infancy and early childhood.

Devotees to any one of these approaches may object to the oversimplification in a one-sentence description of what are often very complex and detailed theories. Also, the list is by no means exhaustive. There are numerous eclectic mixtures. And most of the theories ignore the fact that human beings frequently make mistakes. Human factors researchers who have studied human error rates find them quite high and substantially intractable (Hojjati-Emami, et al., 2015).

Each of the behavioral theories may have some merit for subsets of a population engaged in a given activity at a given time. Human beings are very complicated and, at any one time in the course of a lifetime, several of the factors emphasized by the various schools of thought may influence the behavior of the moment. Therefore, it is not surprising that behavioral or social scientists who have attempted to apply their disparate theories to behaviors that increase or decrease the probability of injury have found one or more of their hypotheses supported to some degree by data. In many such instances, the hypothesis has some predictive value, but in others, the research "results" are artifacts of research design or invalid assumptions about the data or its interpretation.

In one book of contributed chapters regarding mainly psychological theories and their applications to injury-related behavior, several of the authors refer to “determinants” of behavior (Gielen, et al., 2006). Some scientists and physicians with good intentions often write of “the social determinants of disease”. There are no such things. The incidence and severity of disease and injury are probabilistic, not deterministic. The probability of diseases and injuries is increased by exposure to potentially harmful biological agents, physical and chemical agents, genetic propensity, and lifestyles that neglect nutrition and exercise. The prevalent social, economic and political order may lead to increased exposure to such agents or make it difficult for people to be well-nourished. The natural process of aging results in lower resilience to exposure to most agents and the resulting severity of outcome as we grow older. None of these factors are determinative. They increase the probability of disease or injury but most harmful agents must reach a relatively high dosage to reach 100 percent certainty of illness or injury for anyone exposed. Human behavior, like most other phenomena, is not determined; it is probabilistic. One or another biological, cultural, social, economic, or psychological factor, or several in combination, may increase or decrease the probability of a given behavior. No one or combination of them is going to map into a one-to-one determination that a given behavior will occur.

The usefulness of the valid biological, psychological, economic, and social predictors of increased probability of injury depend on the strength of the correlations and the extent to which the factors are subject to change by intervention. A primary concern regarding behavior change is its implementation in large populations. More than six billion people inhabit the earth in a huge variety of societies, cultures, and economies. Even within countries such as the U.S., there are large variances in subcultures based on ethnic background, religion, economic status, age, and sexual orientation to name several.

Some people are organized, formally or informally, around interests that place their adherents at special risk – guns, motorcycles, and turf defense by street gangs among the most prominent. Many thrive on false narratives, such as the need for a loaded gun by one's bed to defend one's home in areas where the risk of home invasion is virtually nil. There is a much greater probability that a child will find the gun and shoot someone or self than that the home will be invaded. The claimed need to defend the home requires an accessible, loaded gun while such availability increases the probability of children’s access or use by an adult in a moment of rage or psychological depression in the case of suicides.

Individuals are often psychologically torn among the mores and expectations of different subcultures in groups to which they belong. To reduce injury by behavior change, the effort must be demonstrated to be effective in numerous contexts and directed at the most vulnerable segments of populations.

A complete explication of behavior theories and their implications for injury research would require far more space than is available for a single chapter. Here I briefly discuss the stages of life to indicate the complexity of the problem. Not only do the causal models of different schools of thought look quite different, but the relative strength of a given causal path in any causal model of injury must also differ dramatically depending on the stage of development of the individual (Kane, 1985). Age is a proxy for a mix of the factors emphasized in behavioral theories as well as the differential vulnerability of tissue to energy insults, and the probability of being in situations where energy exchanges are more or less likely.

DEVELOPMENTAL STAGES IN CHILDHOOD. During 1976-77 in the U.S., the motor-vehicle-occupant death rate per population of infants less than one year of age was twice that of one to two-year-olds. The rate declined, as children grew older until age six when it leveled, and the rate among 6-12-year-olds was about a third that of infants (Baker, 1979). Does this mean that parents were conditioned to love their children more and take better care of them as they grew? Do children increase in utility as they develop? Are the social and economic pressures on new parents so severe that their driving ability deteriorates enormously? Do some new parents have a subconscious hate for their newborn that is manifested in driving behavior, endangering themselves as well as the infant?

Perhaps a few of the behavioral and social scientists extremely dedicated to their respective theories would view such hypotheses as worthy of research, but scientists aware of anatomy and physics considered other hypotheses. The tissues of infants are less tolerant of energy insults and certain positions in the vehicles increase the mechanical forces on them in crashes. Using the formula describing mechanical energy in Chapter 2, it can be shown that an unrestrained ten-pound baby becomes a 300-pound flying object in a 30-mile-per-hour crash. Furthermore, when placed in the lap of an adult, an infant in a frontal crash will be crushed between the interior-front structures of the vehicle and the similarly multiplied weight of an unrestrained adult attempting to hold the infant.

Social and behavioral factors undoubtedly affect the transportation of children in particular types of vehicles, their seating arrangement in the vehicles, and whether or not they are restrained in an appropriate child carrier or booster seat. Children may also distract drivers, but probably no more at one year of age than at six years of age. The relative effects of these factors on injury rates have not been studied in sufficient detail to weight them as contributors to injury.

During 1980-1984 in the U.S., vehicle occupant death rates of children less than 1 year old declined 37 percent and those of 1-4 year-olds declined 25 percent as child restraint use laws were adopted (Robertson, 1989). These reductions were associated with increases in observed child restraint use in urban environments that increased from less than 10 percent (Williams, 1976) to 49 percent (National Highway Traffic Safety Administration, 1989). Children seated in the front seat in vehicles in fatal crashes declined from 42 to 31 percent in the 1990s in association with publicized warnings regarding the danger of passenger airbags to out-of-position children in front seats (Wittenberg, et al., 2001).

Child development may be modified by brain damage associated with low birth weight, in-uterus alcohol, and drug exposure, environmental lead exposure, serotonin deficiency, or head trauma in childhood. Such factors associated with later violent behavior led a National Research Council panel on violence to recommend longitudinal studies to better delineate their potential effects (Reiss and Roth, 1993). In the U.S., falls are the leading cause of head trauma to children less than 12 years of age. Assaults on children are strongly correlated with the presence of adults other than biological parents in the household (Reading, 2006).

As children develop motor skills, they become more active. For a time, motor skills develop more rapidly than perceptual and cognitive skills. Children's injuries reflect the hazards in the environments in which they are placed or find themselves, and the behaviors that expose them to energy exchanges, as well as changing tissue vulnerabilities (Rivara, 1982a). They roll and later crawl, off beds and from other elevated surfaces. Their heads are larger than their bodies, and hanging sometimes asphyxiates those that squeeze their bodies between crib slats. Children attempt to swallow foods and other objects that are of a size to block respiration when lodged in the trachea. Toxic chemicals and plants are also swallowed. They wander into swimming pools, hot tubs, and spas. They touch hot surfaces, pull over containers of hot liquids, and are placed in, or turn on, overheated water. They find loaded guns and occasionally shoot people.

A study of parental actions to reduce injury to toddlers found that attempting to teach the child to avoid hazards was ineffective at best and increased risk in some instances. Hazard removal and parental supervision were more likely to reduce injuries (Morrongiello, et al., 2004).

At given points in development, children learn to largely avoid certain hazards to which they remain exposed in their environments. Head injuries associated with stairs and window or door glass decline by half from age two to three, and those associated with furniture and other household fixtures decline rapidly after age six to seven (Rivara, 1982b). At ages 4 to 9, children playing with matches and lighters start fires, disproportionate to their numbers in the population at that age (Cole, et al., 1986). As they develop the ability to run, climb, and operate vehicles such as tricycles, bicycles, guns, skateboards, and motorized vehicles, children's involvement in injuries associated with these activities increases.

A variety of research questions have been raised by these injury distributions (Rivara, 1982a). To what extent does a differential understanding of developmental stages by parents account for their children's exposure to hazards? If there are differences in knowledge, does giving information to the less informed result in reduced exposure and injuries? What are the capabilities of children relative to proposed countermeasures? For example, if fencing is the option chosen to reduce children's access to swimming pools, what types of fences or gates can children breach (Rabinovich, et al., 1994)? To know how to modify firearms to prevent child use, what is the limit of children's ability to pull the trigger of extant firearms (Naureckas, et al., 1995)?

The age differences in injuries vary by gender in some cases and not in others. Are the differences in males and females learned, biological, or some combination of the two? What other characteristics of children, if any, are predictive of injury given similar exposure to hazards? Are such characteristics short-lived, or do they persist through several developmental stages? How does one distinguish cases of unintentional injury and child abuse (Kemp, et al., 1994)? Are any of the predictive characteristics modifiable, and do attempts at modification result in reduced injury? One review of attempts to reduce antisocial behavior in children indicates that early interventions with prospective and new parents are more effective than later school-based approaches (Tremblay and Craig, 1995). Nevertheless, school and after-school programs have been shown experimentally to reduce aggressive behavior as rated by teachers and parents (Hudley, 2003).

Less often considered are questions regarding stimuli generated outside the home. What influence does advertising have on decisions to purchase hazardous products? How much of such influence is exerted through TV programs and commercials directed at children? How many hazardous products are received as gifts and from whom? How often do the injuries associated with hazardous products occur from products that belong to neighbors, friends, relatives, and others outside the home?

The noted references indicate that epidemiologists and others interested in children's injuries have attempted to answer a few of the questions using a variety of methodological approaches. This is not the place for an exhaustive literature review, which should be undertaken before attempting new research.

ADOLESCENTS AND YOUNG ADULTS. The most severe injuries to teenagers and young adults occur in motor vehicles and assaults, particularly assaults on self or others with guns in the United States (Baker, et al., 1992). Assaults, sports, and motor vehicles topped the list of mechanisms of teenaged head injuries (Quale, et al, 2014). Males are substantially more involved than females as drivers and assailants, Caucasians are more often killed in motor vehicles and suicides, while African-Americans are more often killed in assaults. Females are often involved as "straw purchasers" of guns for males with criminal records and dealers are willing to sell, in some cases even if they know the eventual recipient cannot legally own the gun (Sorenson and Vittes, 2003).

The involvement of teenage drivers in fatal motor vehicle crashes per the number of teenagers in the population has declined by about two-thirds since the Fatality Analysis Reporting System was initiated in 1975 (Figure 10-1). In recent years teenage drivers have been less involved per capita than 20-34-year-olds. When corrected for miles driven, however, teenage drivers have the highest involvement rates relative to drivers up to age 79 (Figure 10-2). The major reason for the decline in Figure 10-1 is that fewer teenagers are driving.

The effects of driver education and graduated driver licenses on teenage driving respectively are discussed in the next two chapters. The cost of insuring teenage drivers may also contribute to the decline in teen driving. Car ownership is lower in U.S. states that have higher insurance rates (Raphael and Rice, 2002) and teen insurance rates can be more than double adult rates in several states. The gender differences among drivers less than 30 years old seen in Figure 10-2 are larger than the age differences but gender gets much less attention than age.

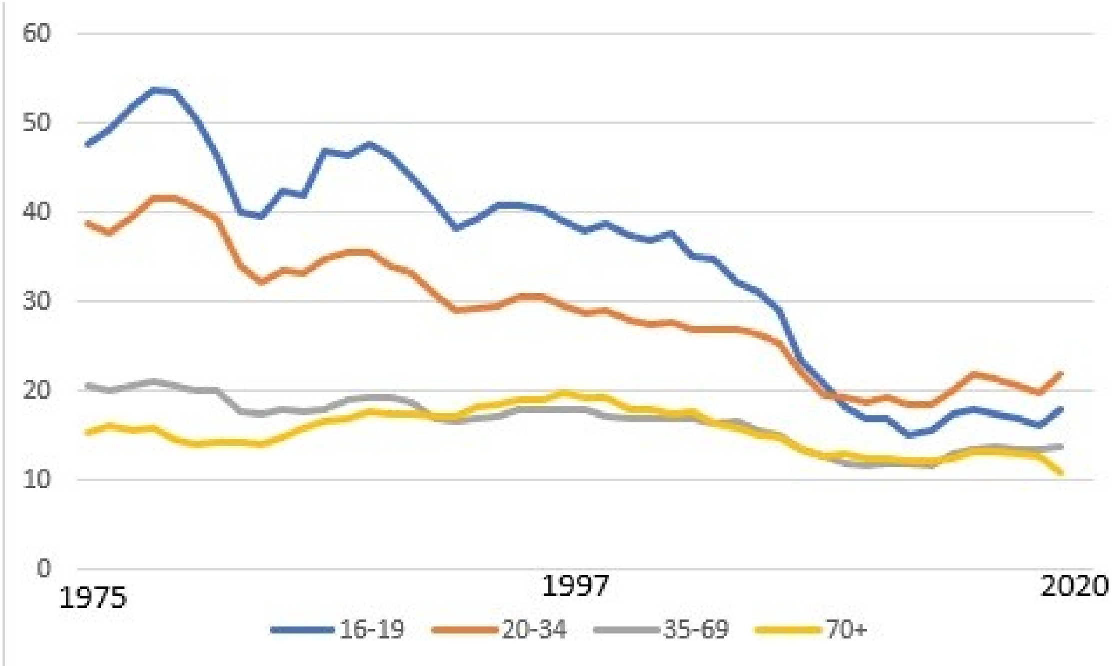

Figure 10-1. **Age of drivers in fatal crashes per 100,000 of the age group in the population.** Source: http://www.iihs.org/iihs/topics/t/teenagers/fatalityfacts/teenagers

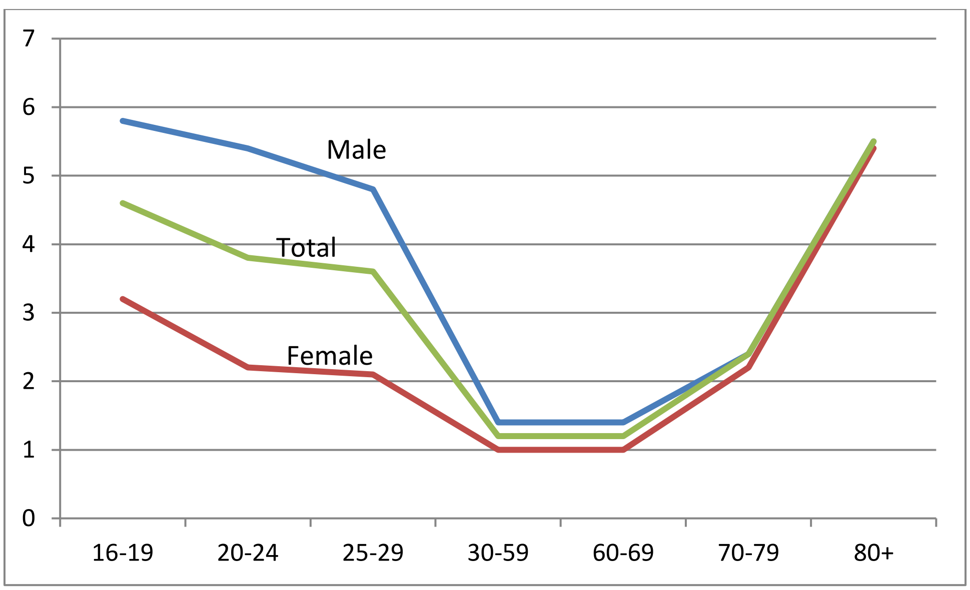

Figure 10-2. Fatal crash involvement per 100 million miles driven by age and gender. Source: http://www.iihs.org/iihs/topics/t/teenagers/fatalityfacts/teenagers

Behavioral theories contain all sorts of hypotheses as potential explanations of teen and young adult behavior, but the research in support of many of them is inadequate or nonexistent. Adolescence and young adulthood is a period of accelerated separation from parental influence, sexual maturity and establishment of sexual relationships, struggle for economic independence, and adaptation to changing expectations from peers and adults (Gilula and Daniels, 1969). Terms such as inexperience, risk-taking, sensation-seeking, impulsiveness, and alcohol and drug abuse are some of the terms used to describe the behaviors of adolescents and young adults that may contribute to injury.

One study in Canada found that motor-vehicle crash rates of newly licensed drivers at ages 17, 18, and 19 were similar to drivers of the same age who had been licensed for one, two, or three years (Pierce, 1977). Therefore, the driving experience did not seem to be a major factor in the substantial decline in crash rates from age 16 to 19. A study of Michigan drivers found the opposite among 18-20 year-olds. Those with two-year driving experience had lower crash rates than those with one year of experience but the age effect persisted in addition to experience. Younger teenage drivers with the same experience as older drivers had higher crash rates (Eby, 1995). In such studies of nonfatal crashes based on police reports, differences in reporting crashes to police, which can be a function of insurance rating and other factors, may bias the results. A study of the prior driving experience of licensed drivers in fatal crashes compared to a sample of same-aged licensed drivers would be more convincing. A case-control study of motorcyclists where the cases were identified from hospital ER cases and coroners indicated a little effect of riding experience but familiarity with the motorcycle made some difference (Mullin, et al., 2000).

Distracted driving has been studied by the use of vehicles equipped to record behaviors and near misses as well as crashes. The association between distracted driving and the outcomes was stronger among teenage drivers than among adults but the confidence intervals on the magnitude of the effects were very large because of the small samples studied (Klauer, et al., 2014; Foss and Goodwin, 2014). A much larger study using onboard cameras estimated that 70 percent of teenaged crashes were attributable to inattention to driving, 58 percent while talking on the phone or to others in the vehicle, texting while driving, etc. The analyzed cases excluded crashes at less than 1 g of force, vehicles hit from the rear, and animal collisions (Carney, et al., 2015). Contrary to estimates of sleepiness being a major factor in teen crashes based on self-reports (e.g., Pizza, et al., 2010), the camera study observed “drowsiness” in less than 1 percent of the crashes. The male/female ratio (52 percent male) was much less than is found in fatal crashes. There may be selection bias in the estimates because the cameras were installed by parents. The motive for the installations is unknown but may have been partly due to parental knowledge that their teens were easily distracted. No comparisons to adult crashes or teen driver behavior when not in crashes were included in the study so precise calculation of the relative risk of the behaviors is unspecified.

The term "risk-taker" implies that the person knows the risk and deliberately behaves in such a way as to increase the risk to themself. Certainly, some suicide attempts and assaults are the results of deliberate choices, but the extent to which perception of risk is associated with various types of risky behavior is difficult to research because of the questionable validity of self-reports of perceptions and behavior (e.g., DeJoy, 1992, Rhodes and Pivik, 2011). The involvement of alcohol, other drugs, and mental illness in many cases of presumed deliberate assaults on self and others raises doubt about the pre-injury state of mind of the persons regarding the perception of risk (Graham, 2003). In addition to or in combination with alcohol use, marijuana use is associated with hospitalization for a variety of injuries perhaps indicative of impaired assessment of risk (Gerberich, et al., 2003).

Caution in driving and other pursuits may be a basic personality characteristic. Teens that react with higher cortisol output during a stressful math test had fewer vehicle crashes during a follow-up period (Ouimet, et al., 2014).

The hypothesis that risk denial or belief in personal invulnerability is a factor is at least as plausible as the "risk-taker" hypothesis. Studies of perceived risk in motor vehicles indicate that younger drivers more often think their peers at higher risk than themselves, compared to such perceptions among older drivers (Bragg and Finn, 1982; Matthews and Moran, 1986), yet the authors of those studies persisted in calling the risk denying young drivers "risk-takers".

Motor vehicle injuries are common enough in the adolescent years such that prospective cohort studies could be undertaken to measure the extent to which genetic and hormonal differences, knowledge of risk, beliefs about personal vulnerability, impulsiveness, mental illness, conflicts with parents and lovers or peers, challenges from peers, and economic difficulties are predictive of becoming a driver in a crash causing injury. Becoming the assailant or the injured in an assault may be subject to study by similar methods, although identification of cases not reported to police would be difficult given the potential for reluctance to report involvement.

Unwarranted conclusions have been drawn from the examination of patients after injury and inference of pre-injury psychopathology. For example, one study of patients in a trauma center, excluding two-thirds (those with a Glasgow Coma Score less than 15 as well as children less than 18 and those receiving narcotics for pain), claimed that the patients had higher than normal "pre-injury psychopathology". The measure of "psychopathology" consisted of a questionnaire with items such as "I feel isolated", and "I have low/very low spirits" (Whetsell, et al., 1989). Administered to people in a hospital after trauma, it should have been obvious to the researchers that these are not necessarily measures of pre-hospital states of mind. No attempt was made to correlate the responses to the behavior of the respondents at the time of injury, i.e., did the respondents' behavior contribute to the injury or not? Prospective studies of questionnaire measures of psychological traits and car crashes do not indicate a correlation (e.g., Schuster and Guilford, 1964), but temporary psychological states are not captured by such methods (Robertson, 1983).

The literature on behavioral factors in assaults and homicides is mainly limited to descriptive studies. Some correlations among the relationship between assailant and victim, weapon if any, and biological, psychological, social, and demographic characteristics have been reported, but there is substantial disagreement regarding causation, partly resulting from numerous methodological issues (Rosenberg, et al., 1986). Characteristics of assailants and interactions among couples in domestic assaults have been described (Shupe, et al., 1987), but no data were collected on couples not involved to be able to say that the alleged causal factors were less prevalent in those who do not have such problems. Comparison of domestic homicides vs. other homicides (Joudis, et al., 2014) or gender differences in firearm suicides (Kaplan, et al., 2009) are of dubious value. The studied people are all dead and without knowledge of the prevalence in the population of the factors identified, the relative risks remain unknown.

Racial differences are emphasized in many studies of homicide because of the very high rates among young African-American males. Studies of domestic homicide indicate, however, that the correlation with race disappears when household crowding is controlled statistically (Centerwell, 1995). Rates of assaults and other crimes of juveniles with single parents plunge when they move from poverty neighborhoods to more middle-class environments in random housing assignments (Ludwig, et al., 2001). It is the socioeconomic consequences of the way races have been treated historically and the criminal cultures that have historically accompanied poverty among a variety of ethnic groups that explains the differences in violence, not the genetics of race. In some cases, poverty is mitigated by cultural factors. It has been claimed that recent Mexican immigrants to the U.S. have substantially lower involvement in violence than would be expected from their economic status (Sampson, et al., 2005), but the claims are based on self-reports which are less reliable than counts of fatal cases. Some immigrants to the United States adapt to the gun culture quickly. Although suicide rates are lower, homicide rates are higher among many immigrant groups than among their counterparts of similar ethnic origin (Sorenson, Sorenson, and Shen, 1999).

Aggression has been studied extensively in controlled laboratory experiments under a wide variety of experimental conditions (Mattson, 2003; Siegel, 2005). The relevance of these studies to assaults in homes, streets, and bars, or to aggressive driving, is open to debate. One well-designed study of alcohol and aggression in college students, for example, randomly divided the students into four groups: 1. alcohol and threatened 2. alcohol and not threatened, 3. placebo and threatened, 4. placebo and not threatened. Strong flavoring masked the alcohol and placebo. The subjects were placed in a situation where they were supposedly competing with a person in another room on a reaction-time task in which each subject could deliver an electric shock to the other. The situation was presumed as threatening, but those in the "non-threatened" condition heard their "opponent" object to hurting someone. There was no difference in the intensity of shock delivered to "opponents" between those with and without alcohol in the non-threatened groups. Those in the threatened group delivered more intense shocks to their "opponents" and, if they had also consumed alcohol, they delivered very strong shocks to their "opponents" (Taylor, et al., 1976).

Given knowledge of such results, an injury epidemiologist wants to know how much of the variation in assaults can be explained by alcohol and threatening situations. How does a researcher obtain unbiased samples of assailants and potential assailants in which alcohol can be measured? What constitutes a threat? Is there a relatively small set of threats that can be identified in large numbers of assault cases? Is the assault directed toward someone perceived as threatening or a scapegoat such as a child, spouse, or lover?

If the set of factors that are threatening to persons who are potential assailants were limited to a few, such as unemployment or fear of unemployment, harassment by peers, and degradation of self-esteem by spouses or lovers, then it may be possible to find ways to help people cope with such threats. If the threats are so diverse that none accounts for a substantial part of the problem, then the probable success of changing threats to reduce assault is diminished.

Among the most publicized claims about the causation of spouse and child battering is that the batterer was abused as a child. While being abused as a child may increase the risk of becoming an abusing adult, the majority of abusers were not abused as children (Rosenberg, et al., 1986). Therefore, as desirable as the reduction in child abuse would be, it would not reduce battering in the next generation as much as the publicized claims would have us believe.

Intimate partner homicide is substantially related to mental illness (Farooque, et al., 2005**).** One way of studying these issues in a population would be to identify from police records a sample of households that had one or more domestic disputes reported within the past year. Controls for comparison could be selected by identifying residents of other households in the same residential block and randomly choosing one or more that had no domestic disputes reported to police in the past year. Interviews with family members, preferably augmented by validity checks where possible -- such as employment history, might reveal a set of threats, mental illness, or other factors that, separately or in combination with alcohol, are amenable to change. Self-reports of violent sexual aggression did not disproportionately involve alcohol use but did involve resistance to alcohol use by the victim (Racket, et al, 2004**).** Various aspects of the involvement of alcohol in violence are covered in more detail by Galanter et al., 2021.

The advantage of police-reported cases is the potential for obtaining objective data on alcohol. A small pilot study could be undertaken to see whether cases and controls would cooperate with a request for breath alcohol, the controls at the same time of day and day of the week as the dispute was reported in the cases.

The study design would be subject to criticism because it would not identify the set of battered women and children that do not come to the attention of the police. Protocols for identifying such cases have been developed (Stark, et al., 1981), and researchers with clinical affiliations should be able to identify many such cases in that setting, but objective measurement of alcohol in the batterer in those circumstances probably would not be feasible. Great care must be exercised in such research to avoid placing the battered person in greater jeopardy for having revealed the batterer, however inadvertently.

Descriptive studies of suicides of teenagers and young adults indicate clusters of types of problems (legal, interpersonal, history of mental illness), method used (firearm, hanging, drugs, gas), and age group (Gerberich, et al., 1985). Case-control studies, such as the Houston study (Silverman and Simon, 2001), are needed to determine which from among the identified factors are risk factors or can be used to identify persons at higher risk. One such finding from the Houston study is that suicide attempters had changed residence more often than controls within the last 12 months. Another design would select cases from each cluster and controls with similar problems to reveal the extent to which suicides within a given cluster are correlated to the misfit of personality and social environment, availability of method used, and other variables in theories of suicide.

Little research has been conducted on attempts to change exposure to potential injury hazards by offering programs to youth that keep them from hazardous environments. In the United States, programs to open schools and other facilities for "midnight basketball" for low-income youth were treated as a joke by political opponents of any government involvement, rather than taken seriously as a program to be studied (Hartman, 2001). Claims of success based on simple trends in crime rates in cities that have the programs are inadequate (Farrell, et al., 1996). Controls on changes in other factors, such as an influx of recent immigrants, are needed to rule out those factors as explanations. In Brazil, some 370 programs to engage so-called "street children" in productive activities were initiated, but the effect on injuries and other problems of these children has not been evaluated (Berger and Mohan, 1996).

A neglected area of research in adolescent and young adult injuries is the extent of recruitment to danger. To what extent is the use of cars and guns in hazardous ways a function of nightly doses of television portrayals of such behavior? To what extent do organized clubs for hazardous activities recruit new participants? What is the involvement of the industries that sell equipment for hazardous activities (e.g, hang gliding, scuba diving, sky diving, motorcycling, gun use, fast cars) involved in promoting the activity through clubs and magazines? How many of the injured were led to the activity by such promotion?

For example, members of the Sports Car Club of America, matched by age and gender to nonmembers, were found to have higher crash rates and speeding violations (Williams and O'Neill, 1974). The unanswered question is whether those who are wont to drive fast join such clubs or are recruited into the club and adopt the speeding culture after joining.

ADULTHOOD. Until recent years, injury rates in the adult pre-retirement years of life were lower than among children and adolescents for most types of injuries. Injuries to workers in certain occupations were major exceptions (Baker, et al., 1992). The generally lower rate of most types of injuries as people proceed through adulthood could be partly from greater knowledge of risks and partly from changes in exposure, such as reduced driving at night and reduced "partying" on weekends. An exception to lower injury rates among preretirement adults is poisoning from opioid drugs. In the 21st Century, death rates due to prescription painkillers have soared, mainly among the 25-64 year age group (Figure 10-3).

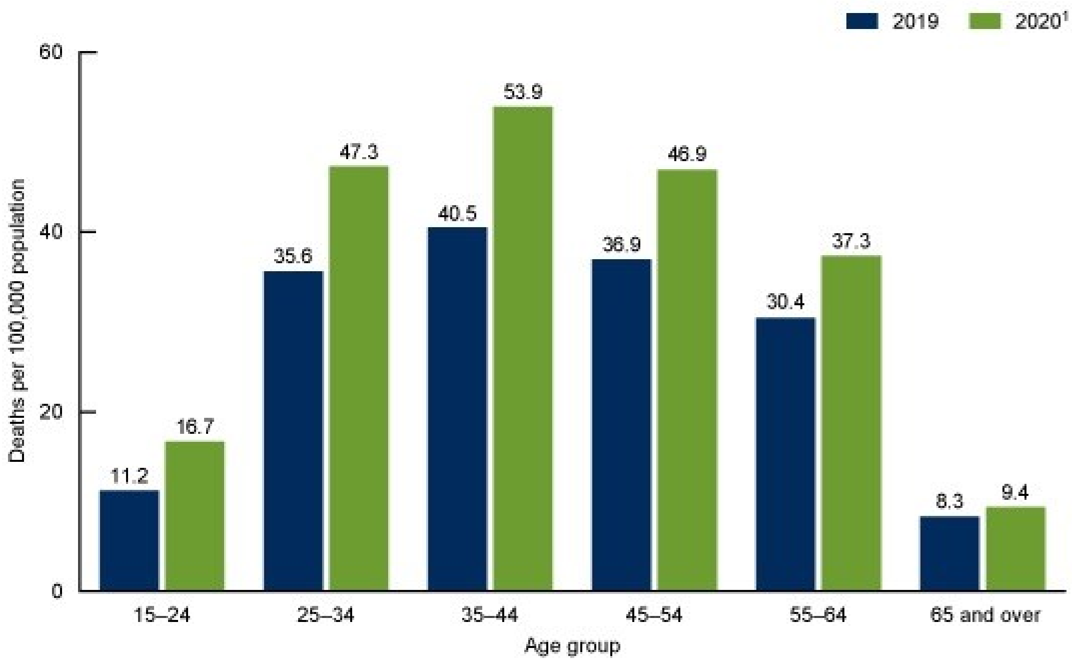

Figure 10-3. Opioid-analgesic poisoning death rates, by age group: United States, 2019-2020.
Source:
https://www.cdc.gov/nchs/products/databriefs/db428.htm#:~:text=Among%20people%20aged%2015%20and,over%20(8.3%20and%209.4).

Following studies claiming that pain was undermedicated, in the 1990s the standard of medical care for use of opium-based drugs was altered to recommend larger doses. The manufacturers of opioids, especially oxycontin, indulged in extensive campaigns to persuade physicians and dentists to increase prescriptions claiming that they are not addictive to people in pain (Keefe, 2021). But that is not true and, in addition to prescriptions, a black market provided the drugs to those who could not get prescriptions. Addicts often become desperate to obtain drugs. In a study of 275 cases of opioid-caused deaths in West Virginia, among the states with the highest drug-caused death rates, less than half had been obtained by prescriptions (Hall, et al., 2008). Doctor shopping for physicians who would prescribe an opioid was found among 30 percent of women and 17 percent of men. Opioid deaths per population are several times as frequent among people in occupations that require physical exertion suggesting that the pre-addictive use of the drugs was motivated by physical pain (Shaw, et al., 2020).

The frequency of types of opioids in fatal poisons changed over time (Figure 10-4). When pill shopping and opioid marketing to physicians and pain clinics were exposed and prescriptions for the drugs were reduced, addicts relied on street heroin for a time in the second decade of the 21st century but the largest increase in drug deaths occurred from synthetic opioids other than methadone that is ordered from China and elsewhere on the internet, mainly fentanyl but also a variety of formulations and mixtures of multiple drugs. Manufactured in facilities with no quality control, the concentration of the synthetic opioids in the products varies widely and overdoses are inevitable. Without international cooperation to shut down the manufacturers and marketing websites, the epidemic is likely to continue (Westhof, 2019).

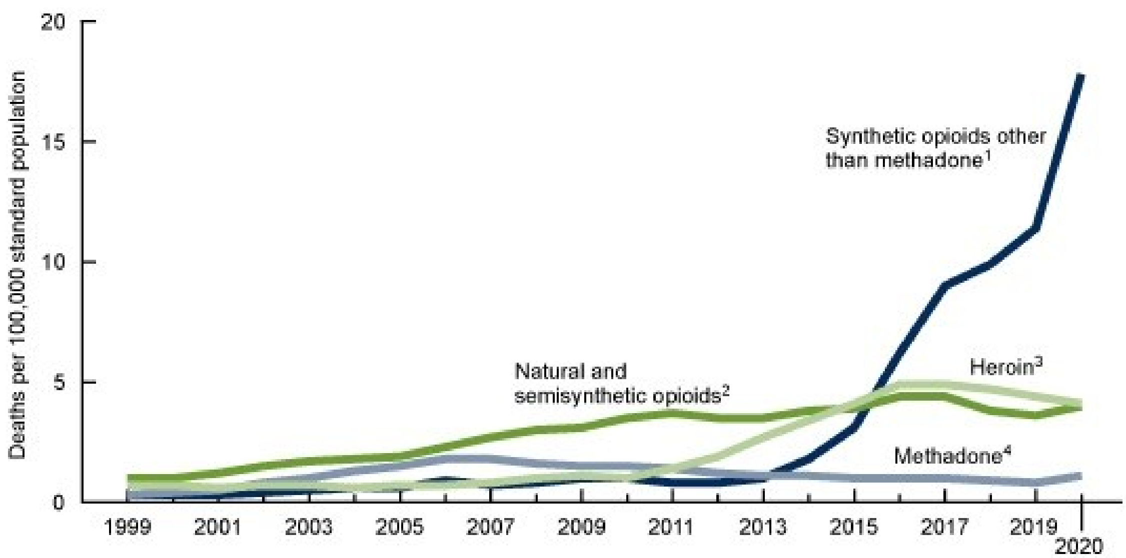

Figure 10-4. Trends in U.S. opioid drug deaths per 100000 population by type of drug. Source: https://www.cdc.gov/nchs/products/databriefs/db428.htm#:~:text=Among%20people%20aged%2015%20and,over%20(8.3%20and%209.4).

The increase in opioid drug use is likely to increase the probability of injuries. in addition to overdoses. As seen in Chapter 1, a reversal in the decline in fall and suicide deaths occurred at about the time that drug deaths began their enormous rise. A study in Sweden found that fall injury increased with the onset of opioid drug use by individuals, particularly pronounced in the first week of drug use (Soderberg, et al., 2013). The increase in suicide has also been linked to increased opioid use (Braden, et al., 2017; Rockett, et al., 2018).

In a study of death certificate data nationally in the U.S., drugs indicative of treatment for mental disorders were found in significant numbers in combination with opioids -- 30 percent benzodiazepine (a sedative and muscle relaxant) and 13 percent antidepressants (Jones, et al., 2013). Risk of death is also associated with higher prescribed dosages except among dying patients in palliative care (Bohnert, et al, 2011). Some “overdose” deaths may be partly attributable to drug interaction effects. A comparison of patients prescribed opioid analgesics in combination with benzodiazepine and patients prescribed only opioids found that the risk of death attributed to overdose more than doubled with the addition of benzodiazepine (Park, et al, 2015).

There is little evidence that personality traits are related to injury risk or perceived risk. Psychometric methods are found inadequate to explain differences between actual and perceived risk (Sjoberg, 2000). Injury risk is higher among the mentally ill. Repeated hospitalizations for unintentional injury were more than twice as frequent among the mentally ill as among other patients treated for an injury in one study (Wan et al., 2006). Suicide risk is 20-30 times higher among victims of bipolar disorder than those without the disease (Pompili, et al., 2013). Failure to take prescribed drugs and self-medication with alcohol and other substances is associated with violence by the mentally ill (Swartz, et al., 1998).

A major factor in changing behavior is overcoming the denial that one is susceptible to a known or perceived risk. After presenting the risks of gassing, hand burns, and child poisonings from household cleansers to a sample of consumers, they were asked how much more or less likely than average such injuries were in their homes. Only 2-3 percent said more likely and 40-65 percent said less likely (Viscusi and Magat, 1987). These results are similar to those obtained when a random sample of new-car buyers was asked whether their chances of being injured or killed in a car crash were greater than, the same as, or less than "people like yourself." Six percent said greater and 40 percent said less. Denial was not related to claimed willingness to pay for improved crash protection in motor vehicles, however (Robertson, 1977). An interesting research project would be to see if denial of risk is associated with the actual probability of injury but the study would have to be done prospectively because denial may be influenced by injury experience.

Race and gender differences that persist in particular types of injury rates are often cited, but race and gender are no more modifiable than age. They are of interest only as identifiers of groups in which causal factors differ in kind or magnitude, or as identifiers for targeting programs to modify risk factors.

Too often conclusions about race and gender are based on stereotypes. In the 1980s when I told colleagues I was reviewing the literature on injuries to Native Americans, virtually everyone stated with conviction that alcohol accounted for the higher injury rates in that population. The literature indicated that, while alcohol is a problem among several Native American groups, it probably does not account for nearly the variation in injury rates that stereotypical thinking suggests. The only study found in which blood alcohol was measured among injured Native Americans indicated that more Native Americans were tested in the same jurisdiction relative to whites, 63 percent versus 45 percent (Westermeyer and Brantner, 1972). Therefore, the involvement of alcohol measured objectively was not available in a sample without potential selection bias. A later study of Native Americans and others in fatal motor vehicle crashes in Arizona relied on invalid police reports for the majority of assessments of alcohol in Native Americans (Campos-Outcalt, et al., 1997). Although the article claimed that there was no difference in the proportion chemically tested for alcohol concentration, recalculation of the numbers in the article indicates that 33 percent of Native Americans were tested and 56 percent of others were tested. If the police were more oriented toward expecting alcohol in Native Americans, the estimate of alcohol involvement would be biased.

There was a 29-fold difference in deaths attributed to "alcoholism", cirrhosis, or alcohol poisoning among different groups of Native Americans in Oklahoma (Stratton, et al., 1978). Age-adjusted alcoholism death rates among Native Americans declined by about 40 percent in the early 1980s (Howard, et al., 2000). Self-reported total abstinence from alcohol is twice as high among Native Americans as among Caucasians. In groups where intoxication is frowned upon, drinking is done alone and in secret. In groups with a tradition of seeking visions and endurance dancing, heavy alcohol consumption in public is more acceptable, particularly among young males (Levy and Kunitz, 1974; Kunitz, 1976; May, 1982). The stereotype likely evolved from historical accounts of "Indians and firewater" and the very noticeable public drinking in certain groups, particularly in towns near reservations.

The social factors that influence if, when, and where drinking occurs undoubtedly influence the risk of particular types of injuries, such as the high rate of deaths from cold and exposure among Native Americans in New Mexico (Sewell, et al., 1989). Before declines associated with injury control programs for Native Americans (Smith and Robertson, 2000), Native Americans who obtained medical care from the Indian Health Service had about three times the injury death rates of the United States population as a whole. When I compared the total injury death rates of Native Americans with those of rural isolated populations generally, however, the differences were small (Robertson, 1985).

Among U.S. Navy personnel, Native Americans were hospitalized for "alcoholism" three times more often per capita than Caucasians or African Americans, yet their hospitalizations for injury per capita were 13 percent less than those for whites and African Americans (Hoiberg, et al., 1981). The point is that injury rates are similar among races whose living and working conditions are similar. The major explanations for racial differences in injury rates are more likely to be found in the vehicles and environments to which they are exposed rather than in biological and personality theories, or racial stereotypes. According to a CDC WISQARS death certificate search, the age-adjusted Native American injury death rate declined to 1.12 times higher than the Caucasian rate by 2020. The rates among those who are served by the Indian Health Service are higher but have declined more rapidly than among the U.S. population generally in association with surveillance activities and evidence-based injury control programs (Chapter 7).

The extent to which gender differences in injury rates can be attributed to biological factors, social factors, or interaction among biological and social factors, probably differs by type of injury. Women usually experience fewer severe injuries of most types as teenagers and adults, but there are exceptions. In domestic violence that does not involve weapons, women often strike men as well as vice versa, but the severe injuries from violence in homes are most often to women and children (Rosenberg, et al, 1986), probably because men are physically stronger, on average than women and children. Most of the studies of dominance behavior, hormones, alcohol, and other potential factors in aggressive behavior have not included women (Mazur and Robertson, 1972).

GROWING OLD. Severe injury rates tend to increase among the elderly for several types of injury (Rice and MacKenzie, 1989). Although some exposures are decreased among the elderly (e.g., miles driven, driving at night), and injury incidence is lower, the consequences when an injury occurs in length of hospital stays and mortality are more severe because of decreased resilience to trauma. Decreases in visual acuity, hearing, and mental alertness, as well as multiple prescription drug use probably increase the risk of incidence, but reduced exposure to driving, industrial machines, and farm equipment probably result in lower incidence. Certain exposures, such as the use of stairs or walking on other surfaces that are conducive to falls, are not changed or may even increase after retirement. The elderly have particularly high injury rates from falls. In social environments where the young prey on or abuse the elderly, they are the victims of assault, and some resort to suicide to escape social circumstances or physical debilitation that they are no longer willing to tolerate.

Elderly people suffer various types of losses including friends, spouses, occasionally a child, job, status, income, power, self-esteem, self-confidence, hearing, sight, other aspects of personal control or competence, and health, all of which are thought to contribute to suicide (Osgood, 1985). In a case-control study in Sweden, suicide risk was substantially higher in persons with visual impairment, neurological disorders, and malignancies (Waern, et al., 2002). Many among the elderly support the availability of physician-assisted suicide for the terminally ill, such as that first allowed by law in Oregon and now several other U.S. states as well as countries elsewhere. Combined homicide-suicide among the elderly, where the involvement of guns predominates, has been studied by case-control methods (Malphurs and Cohen, 2005).

The exact contribution of exposure to energy exchanges by the degree of energy generated versus tissue vulnerability to particular types of energy among the elderly has not been specified. Certainly, the injured elderly person with the same degree of severity as a younger person is more likely to die than the younger person (Baker, et al., 1974) which probably accounts for much of their high involvement in fatal crashes per mile driven (Figure 10-3).

A big question raised by the trends in age-related opioid poisoning is why a relatively low rate of increase among the elderly. Pain for which the drugs are prescribed is more frequent and severe among the elderly than among younger people because of arthritis and deteriorating bone structure. Do physicians consider these pains less worthy of opioid prescriptions? Are the elderly less susceptible to addiction? Are the elderly less willing to doctor shop or obtain drugs illegally? Or are drug deaths among the elderly more likely to be attributed to other causes?

Attention to the risk of falls in the elderly has increased. Among the factors related to falls potentially amenable to change are leg extension strength and gait (Graafmans, et al., 1996; Tinetti, et al., 1995a) and modifiable environmental factors, such as characteristics of stairs (Tinetti, et al, 1995b), which have been found markedly different between the homes of fallers and controls in a case-control study on an Indian reservation (Locklear, 1991). The use of video footage in elder care facilities can further specify the circumstances of falls (Rabinovitch, et al., 2013). Studies of falls refer to relatively strong correlates (multiple pharmaceuticals use, visual acuity, and fear of falling) as predictors (Delbaere, et al, 2006) but do not consider how many false positives and false negatives occur in such predictions. That information is important to apply countermeasures efficiently.

POST-TRAUMA BEHAVIOR. Combat veterans have higher injury rates than other military veterans. Various hypotheses have been advanced to explain this finding but none have been tested adequately (Bell, et al., 2001). There are many studies of posttraumatic stress disorder among combat veterans compared to veterans and others not in combat but the sample sizes are too small to detect subsequent injury risk (e.g., Koren, et al., 2005). A large-sample study comparing veterans with and without traumatic brain injury (TBI) found suicide risk is about twice as high among those with TBI (Hostetter, et al., 2019). Self-reports of combat experience are correlated to self-reports of alcohol use known to increase the risk of injury (Wilk, et al., 2010).

The lives of persons with non-corrected disabilities are changed -- drastically in the case of severe spinal cord and brain injury. Documentation of the extent of these effects is important to understand the total, often non-quantifiable, costs of injury. A comparison of injured and non-injured controls would better specify the effect of war experiences.

Other effects of an injury may be subtler or not appear immediately. How many people change their behavior as a result of an injury? What is the effect on subsequent fear and anxiety of trauma to oneself or relatives and friends? To what extent does neighborhood violence change the behavior patterns of people in the neighborhood? Does fear of falling result in less mobility among the elderly

(Tinetti, et al., 1994), further contributing to the risk? Does subtle brain injury contribute to intellectual or emotional deficits, or increase the risk of brain diseases such as dementia and epilepsy (Gardner, et al., 2015; Johnson and Stewart, 2015; Lucke-Wold, et al., 2015)?

Some of these questions raise thorny methodological issues. To the extent that the hypothesized effect of trauma could also contribute to the incidence, post-trauma measurement may overstate the effect of trauma. For example, one research project measured the intelligence quotients of persons who had been injured and correlated them to the injured persons' scores on the Glasgow Coma Scale and the Injury Severity Score. Persons who were more severely injured had lower IQs (Gensemer, et al., 1989). However, if lower IQ contributes to the probability of severe injury, the inference of a causal effect of trauma on IQ would be overstated. A correlation between lower pre-crash IQs (measured at army induction) and fatal motor vehicle injury has been found (O'Toole, 1990).

Where pre-injury measures are available, such as IQ scores from school, military, or other records, researchers interested in post-trauma effects should attempt to obtain the records. Where such measures are not available, the IQ of a sample of siblings or childhood friends of the injured could be used for comparison. To the extent that IQ is predictive; the issue of limits to the modifiability of IQ is relevant to the choice of injury control methods.

Case-control studies of Alzheimer's disease consistently find a history of head trauma more frequent in persons with the disease -- 24 percent of cases and 8 percent of genetically unrelated relatives and friends matched by gender and approximate age in one study (Graves, et al., 1990). The odds ratios were higher for those whose head injury did not result in loss of consciousness and among those with more recent head trauma. Although there are reasonable biological explanations for head trauma contributing to the disease and the average period between the head trauma and onset of symptoms minus one year was long -- 21.3 years for cases -- it is not possible to exclude the disease or some correlate of the disease as a precursor to trauma rather than exclusively a post-trauma effect.

A study of recalled loss of consciousness from injury found no association with dementia while following elderly participants every two years. Those with a claimed history of loss of consciousness did experience more injuries during the study period (Dams-O'Connor, et al., 2013). A review of recent research is available online (Smith, et al., 2013). It would be useful to compare cases in which the behavior of the person did or did not contribute to the injury, but recall of spouses or others regarding long past incidents is a major methodological problem.

Appendix 10-1. Weather, Climate, and Exposure to Risk of Road Death

Age-adjusted road death rates per population in the U.S. declined by about 50 percent from 1980 to 2014 (Chapter 1). The trend abruptly reversed during 2015-2016. Based on counts in the Fatality Analysis Reporting System (FARS), there were 34910 road deaths in 2015 and 37230 in 2016 in the 48 contiguous U.S. states, 7.2 percent, and 14.4 percent respectively more than the 32553 deaths in 2014. Recent research found that warmer average daily temperatures were strongly associated with higher rates of road deaths per population potentially exposed to those temperatures on a given day in urban areas of the U.S. during 2014. Miles traveled per person increased in association with rising temperatures and walking or pedal cycling on roads likely increased as well. Based on a logistic regression model of proxies for risk factors, the increase in deaths in 2015 was mainly associated with increasing temperatures in the urban areas controlling statistically for other risk factors (Robertson, 2017). A study of the national trends in unemployment and road deaths reported that the increase in deaths in 2015 "can be tied primarily to the improving economy" (Farmer, 2017). One of these conclusions is certainly incorrect and both could be.

Previous research on weather conditions correlated to road death risk focused mainly on the effects of rain and snow (e.g., Eisenberg and Warner, (2005); Lee, et al., 2015). These studies emphasized risk given that people are on the roads and did not analyze the potential effect of temperature and precipitation on exposure, that is, the decision to stay indoors during periods of colder temperatures or precipitation. Examination of average monthly temperatures among U.S. states indicated that increased miles driven and higher road death rates per population among the contiguous 48 U.S. states were associated with warmer annual temperatures averaged monthly. The magnitude of the correlation was similar to that found using average daily temperature and fatalities per potentially exposed population at those temperatures in the 100 most populous urban counties. Little fidelity in the correlation between temperature and death rates was lost using monthly data among the states (Robertson, 2018). The weather stations that report temperature are concentrated in or near population centers so that the data are not substantially affected by readings from the thinly populated desert and mountain areas (National Oceanic and Atmospheric Administration, 2017a).

Numerous studies of time series of road deaths in various countries found that road deaths decline temporarily during economic recessions – the recession indicator usually being unemployment (e.g., Haque, 1993; Wegman, et al., 2017). Several theories and studies have suggested that stress, changes in alcohol use, and reduction in commercial truck traffic explain the correlation (e.g., Leigh and Walden, 1991; Cotti and Tefft, 2011; He, 2016). One study found fluctuations in the gross domestic product (GDP) per capita, physicians per population, urbanization, and vehicles per population related to fluctuations in road deaths but unemployment was not so related when the other factors were controlled statistically (Rezaei, et al., 2015). Since GDP contraction for two or more quarters is the definition of recession, the lack of additional effect of unemployment is not surprising. In contrast to the time series studies, a comparison of average road death rates during 1999-2003 with average unemployment among U.S. states indicates higher road death rates in states with high unemployment when controlling other risk factors statistically (Greenwalt, 2006).

The main issue addressed here is not death reductions during recessions but the factors that contributed to an abrupt reversal in the trend of road deaths five years after unemployment peaked. The U.S. unemployment rate declined rather steadily from 10 percent in October 2010 to 5.6 percent in December 2014 (Bureau of Labor Statistics, 2018) while age-adjusted road death rates were declining as well, contrary to the theory that reduced unemployment would increase the deaths. Unemployment declined less than a percentage point during 2015-2016 but road deaths increased by 14 percent.

Additional factors correlated to changes in fatal crash rates in time are changes in motorized vehicle mix (cars, trucks, motorcycles, and busses), vehicle density per population, the age distribution of the population, insurance expenditures, gasoline prices, and increased use of electronic devices while driving. Pickup trucks and truck-based "sports utility vehicles" that are heavier than most passenger cars increase the deaths of occupants of other vehicles (White, 2004) and have higher rollover death rates than passenger cars because of too high a center of gravity relative to track width (Robertson and Maloney, 1997). Motorcycles have a death rate some 34 times that of other vehicles per mile traveled (Lin and Kraus, 2009). Trucks, buses, and motorcycles kill more pedestrians per mile driven than passenger cars (Paulozzi, 2005). Research on the introduction of required liability insurance by states in the 20th Century correlated the requirement with an increase in road deaths, inferring that insured drivers were less cautious (Cohen and Dehejia, 2004). Car ownership is lower when insurance rates are higher among U.S. states (Raphael and Rice, 2002). Road death rates fluctuate inversely to gasoline prices (Grabowski and Morrisey, 2004). Use of electronic devices while driving increases risk (e.g., Wilson and Simpson, 2010) but a national probability sample of observations of drivers indicates that the use of electronic devices while driving declined steadily from 5.2 percent in 2012 to 3.3 percent in 2016 (National Highway Traffic Safety Administration, 2017). The data are not available for each state but the decline in the use of such devices indicates that the use of electronic devices is unlikely to have increased road deaths in 2015-2016.

The death rate per population varies widely among U.S. states. In 2016, for example, 14 states had death rates of 15 per 100,000 populations or more while 16 states had rates of 10 or less (Insurance Institute for Highway Safety, 2018a). The use of state data allows more refined estimates of the association of road deaths to changes in most of the mentioned risk factors. The purpose of this study is to better distinguish the role of increased temperatures, declining unemployment, and changes in the other mentioned factors as predictors of the increased death rates in 2015-2016.

I examined the death rates per month of potential exposure to average monthly temperatures for subsets of road deaths – car and truck occupants, pedestrians, motorcyclists, and pedal cyclists – combining 2011-2016 data to reduce variability related to small numbers at extreme temperatures. I employed least squares regression to examine the association of national trends in unemployment, vehicle miles traveled, linear trend, and deaths. I also used least squares regression to examine the miles driven per vehicle among the states predicted by average annual temperature, precipitation, unemployment, insurance expenditures, and gasoline prices. I used logistic regression models based on 2015-2016 data, separately, to estimate the total number of deaths that would have occurred if each of the variables in the model had not changed from the previous year (Selvin, 1991). In addition to temperature, precipitation, unemployment, and insurance expenditures, I included vehicles per population in each state, percent trucks of registered vehicles, percent motorcycles of registered vehicles, and percent busses of registered vehicles. The data sources are listed in Table 10-1.

Table 10-1. Variables and Sources Used in the Analyses
Road deaths --Fatal Analysis Reporting System, ftp://ftp.nhtsa.dot.gov/fars
Population -- U.S. Census Bureau,
https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
Temperature -- National Oceanic and Atmospheric Administration,
ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/
Precipitation -- National Oceanic and Atmospheric Administration,
ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/
Unemployment -- Labor force statistics from the current population survey.
https://data.bls.gov/timeseries/LNS14000000
Registered Vehicles -- Highway Statistics,
https://www.fhwa.dot.gov/policyinformation/statistics.cfm
Insurance Expenditures --Insurance Information Institute,
https://www.iii.org/fact-statistic/facts-statistics-auto-insurance
Gasoline Prices -- U.S. Energy Adm., https://www.eia.gov/state/seds/seds-data-complete.php?sid=US#CompleteDataFile
Vehicle Miles -- IIHS, http://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/overview-of-fatality-facts
Driver licensure -- Highway Statistics,
https://www.fhwa.dot.gov/policyinformation/statistics.cfm
New Vehicle Sales – Federal Reserve
https://fred.stlouisfed.org/series/TOTALSA

When I found the association of unemployment and road death risk among U.S. states in 2014-2016 inverse to that reported in studies claiming a negative correlation, I examined the relationship between unemployment and road death risk as well as the other risk factors among the states for each year from 2000 through 2016. I counted fatalities during 2000-2016 in the files of the Fatal Analysis Reporting System (FARS), a census of U.S. road deaths gathered by the National Highway Traffic Safety Administration if the death occurred within 30 days of the crash. Since temperature and precipitation data are not available for Alaska and Hawaii during all the years studied, I used data for the 48 contiguous U.S. states. I obtained the average temperature and precipitation per month for each of the included states during 2000-2016 from the files of the National Oceanic and Atmospheric Administration. The weather and death data include different codes for states so I matched them with a computer routine. Highway Statistics provided data on vehicle registrations by type and annual miles driven per state. I obtained population numbers and the median age of the population in each state from the U.S. Census Bureau website. I found a convenient downloadable file of unemployment data for each state compiled by the Rhode Island Department of Labor and Training (2017) using U.S. Department of Labor statistics. I obtained average insurance expenditures for liability coverage by state from data compiled by the National Association of Insurance Commissioners available on the Insurance Information Institute website. Although new vehicle sales are not available by state, I obtained new vehicle sales per month nationally from the Federal Reserve Bank of St. Louis (2018) and compared them to unemployment rates.

When I found that insurance expenditures were inversely related to road deaths per population, I examined the correlation of insurance expenditures to driver licenses per population in different age groups, controlling statistically for unemployment and gasoline prices among the states. I derived gasoline prices among the states from energy consumption. The number of drivers licensed by age is from Highway Statistics and the number of the population by age group in each state is from the U.S. Census Bureau.

Figure 10-5 displays the relation of types of road deaths per population by average monthly temperature (F) in the months in which the deaths occurred during 2011-2016. Each point in the graph is the sum of deaths of a given type of road user in a month when the average temperature was at the indicated average divided by the sum of the populations in the states during months when the temperature was at the indicated average. Per population potentially exposed, deaths of motorcyclists and pedal cyclists are rare at average monthly temperatures below freezing and increase as temperatures rise above that point, then level off at temperatures in the 60s, 70s, and low 80s but pedal cyclist deaths decline a bit at the highest temperatures. Vehicle occupant deaths other than motorcyclists gradually increase on average as temperatures rise but accelerate in the 70s and 80s. The trend in pedestrian deaths is less pronounced. The total death rate increases linearly as temperatures rise (R2=0.81).

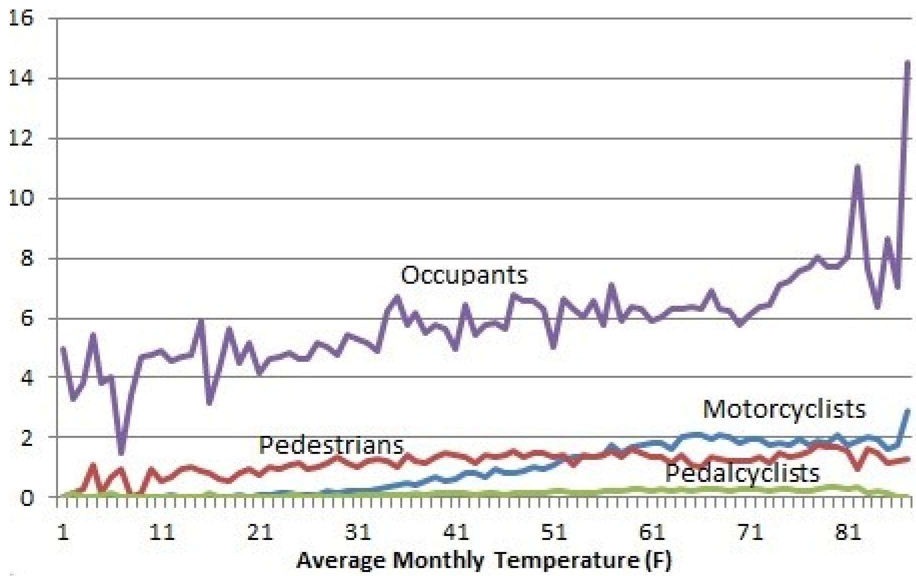

Figure 10-5. Road Deaths Per Million Person Months of Potential Exposure: 48 Contiguous U.S. States, 2011-2016

The conclusion that unemployment explained the 2015 reversal in the road death trend was based on the regression of the national time series of road deaths by linear trend and percent unemployed (Farmer, 2017). The model using data from 1990-2015 was:

Log(deaths)= -3.2449 -.0233 (calendar year – 1989)-.021(percent unemployed)+.962(log(100 million vehicle miles)).

When I analyzed the data obtained from the same sources, I got the same coefficients for the predictor variables but the intercept was -2.744. The collinearity of two predictor variables, calendar year and 100 million vehicle miles was severe (R^2=0.855). Regression coefficients based on predictors that are virtual substitutes for one another are unreliable (Selvin, 1991). Farmer (2017) does not mention why he used 1990 as the beginning point. The data are available beginning when the Fatal Analysis Reporting System was initiated in 1975 and is available on his employer's website (Insurance Institute for Highway Safety, 2018).

To test the predictive value of the model, I estimated the parameters of the regression equation based on the first half of all the available data (1975-1995) and used the equation to compare predicted deaths with actual deaths in the subsequent years (1996-2016). The parameters in this model are:

Log(deaths)=29.147+.0244 (calendar year – 1974)-.057(percent unemployed)-1.273 (log(100 million vehicle miles)).

Collinearity of calendar year and miles was even more severe during 1975-1995 (R^2=.982). Notice that the signs on the coefficients for the calendar year and 100 million vehicle miles are reversed from Farmer's 1990-2015 regression -- negative to positive on the calendar year and positive to negative on 100 million vehicle miles. The coefficient of unemployment is more than twice that in Farmer's equation. The comparison of predicted and actual deaths generated from this equation is displayed in Figure 10-6.

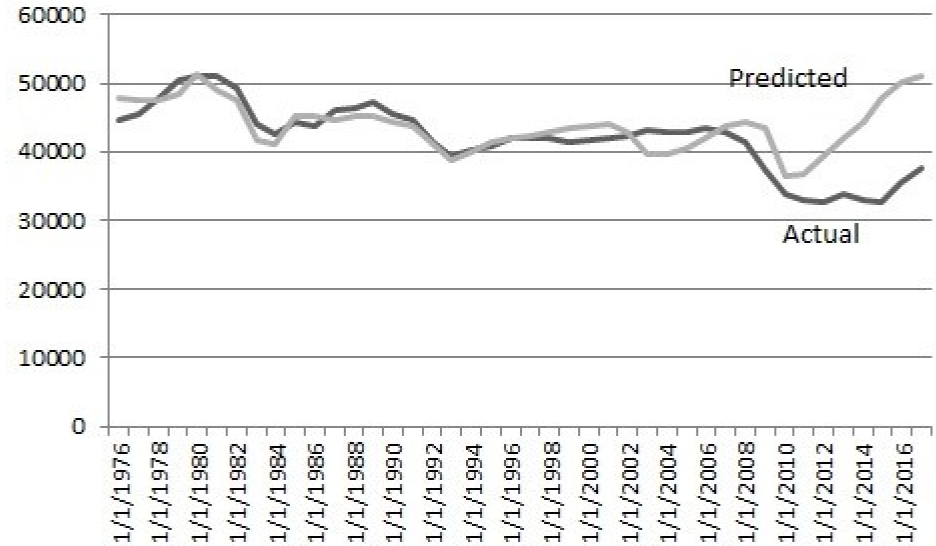

Figure 10-6. U.S. Road Deaths Predicted by Vehicle Miles Traveled, Linear Trend and Unemployment Compared to Actual Deaths, 1975-2016.

Soon after the end of the period used to estimate coefficients in the model (1975-1995), the predicted deaths increasingly diverge from the actual number. The predicted deaths increased from 11 percent higher than actual deaths during 2010 to 37 percent more than occurred in 2016. The model has no predictive value. Furthermore, there is no indication in predictions from this model that unemployment accounted for the 7.2 percent increase in deaths from 2014 to 2015. The model predicted rapidly increasing deaths from 2010 onward as unemployment declined while actual deaths did not increase substantially until 2015.

To examine the association between the risk factors and deaths among states, I used a logistic regression model that reliably predicted increases in road deaths among the states in the 1960s before the onset of a variety of preventive efforts (appendix 9-1). I added unemployment and insurance expenditures to the model to test the unemployment and insurance hypotheses as well as gasoline prices which could affect miles driven. The parameters of this model are:

Log(odds of death per population) = Intercept +
b1 (Average annual temperature (F)) +
b2 (Annual precipitation in inches) +
b3 (Percent unemployment) +
b4 (Average liability insurance expenditures) +
b5 (Average gasoline price per gallon) +

b6 (Registered vehicles per population) +
b7 (Percent trucks of registered vehicles) +
b8 (Percent motorcycles of registered vehicles) +
b8 (Percent busses of registered vehicles) +
b10 (median age of the population)

For each of the years 2000-2016, I estimated the logistic regression coefficients (b 1-10) of the predictor variables using state data (Table 10-2). The coefficients for unemployment fluctuate wildly, nonsignificant or negative three years after the 2001 economic recession, near zero or nonsignificant during and after the 2008-2009 recession but strongly positive during other periods including 2014-2016. Except for a few years during and after recessions, deaths per capita are higher in states with higher unemployment rates controlling statistically for the other risk factors. The coefficients for vehicles per population, percent of motorcycles per registered vehicle, and percent busses of registered vehicles fluctuate substantially from year to year.

Table 10-2. Logistic Regression Coefficients of Predictor Variables Related to Deaths per Population, 48 Contiguous U.S. States, 2000-2016

Year	% Unemp.	Insurance, 100	Gas Price	Temp.	Precip.	Vehicles/ Pop.	% Trucks	% Motorcycl	% Busses	Median Age	Intercept
2000	0.0093	-0.084	-0.948	0.016	0	-0.265	0.023	-0.015	0.374	0.04	-9.098
2001	0.03	-0.086	-0.767	0.017	0	-0.209	0.02	0.047	0.303	0.028	-10.089
2002	-0.021	-0.089	-0.765	0.018	0.002	-0.898	0.024	0.053	0.109	0.027	-9.383
2003	-0.015	-0.086	-0.542	0.02	0.001	-0.614	0.018	0.043	0.145	0.026	-9.613
2004	-0.029	-0.097	-0.6	0.026	0	-0.745	0.017	0.032	0.159	0.027	-9.363
2005	0.047	-0.082	-0.913	0.025	-0.002	-0.294	0.018	-0.019	-0.064	0.056	-10.171
2006	0.041	-0.07	-0.728	0.02	-0.002	-0.28	0.023	-0.047	-0.009	0.043	-9.8
2007	0.023	-0.081	-1.14	0.017	-0.011	-0.342	0.022	-0.065	0.535	0.067	-8.865
2008	0.008	-0.078	-0.816	0.022	0.001	-0.192	0.025	-0.011	0.393	0.034	-9.287
2009	-0.007	-0.089	-0.702	0.019	0.002	-0.157	0.022	-0.008	0.455	0.027	-9.36
2010	0.009	-0.084	-0.948	0.017	0	-0.265	0.023	-0.015	0.374	0.04	-9.098
2011	-0.008	-0.074	-0.618	0.018	0.002	0.155	0.034	-0.053	0.315	0.066	-11.536
2012	0.013	-0.055	-0.202	0.025	0.002	-0.042	0.056	0.033	-0.002	0.068	-15.069
2013	0.032	-0.038	-0.044	0.027	0.003	-0.042	0.056	0.068	-0.24	0.036	-14.88
2014	0.037	-0.036	-0.249	0.028	0.001	0.417	0.053	0.009	-0.185	0.046	-14.626
2015	0.079	-0.049	-0.158	0.031	0.001	0.162	0.046	0.049	-0.124	0.039	-14.665
2016	0.071	-0.019	0.027	0.034	-0.002	0.681	0.04	0.001	-0.11	0.049	-15.752

The most consistent coefficients among the years are those for average monthly temperature, percent trucks of registered vehicles, insurance expenditures, and gasoline prices, indicative of higher death rates during warmer temperatures, more trucks as a proportion of all vehicles, and lower fatality rates in states with higher insurance costs and higher gasoline price. Deaths per capita were also consistently higher in states with older populations, controlling for the other risk factors. These coefficients for median age are the reverse of those found in the 20th Century. The post-World War II increase in births resulted in an increase in higher-risk young drivers during the 1960s and 1970s. The surviving drivers are now near retirement age and licensure of teenaged drivers in raw numbers and per capita declined substantially in the early 21st Century. The decline in death rates among children aged 5-14, teenagers, and young adults in the last quarter of the 20th Century and the first 10 years of the 21st was much more pronounced than among those 30-70 years of age. Figure 10-7 shows the death rates by age group during 1975 (black bars) when FARS first became available and 2010 (grey bars).

Involvement of drivers 16-19 years old in fatal crashes declined from about 38 per 100,000 people in that age group during the year 2000 to less than 20 per 100,000 in 2014 related to declines in licensure. Teenage unemployment is not available for each state but the percent teenagers licensed to drive related to total percent unemployment among states as well as insurance expenditures and gas prices suggest an impact of economic factors on licensure to drive in that age group.

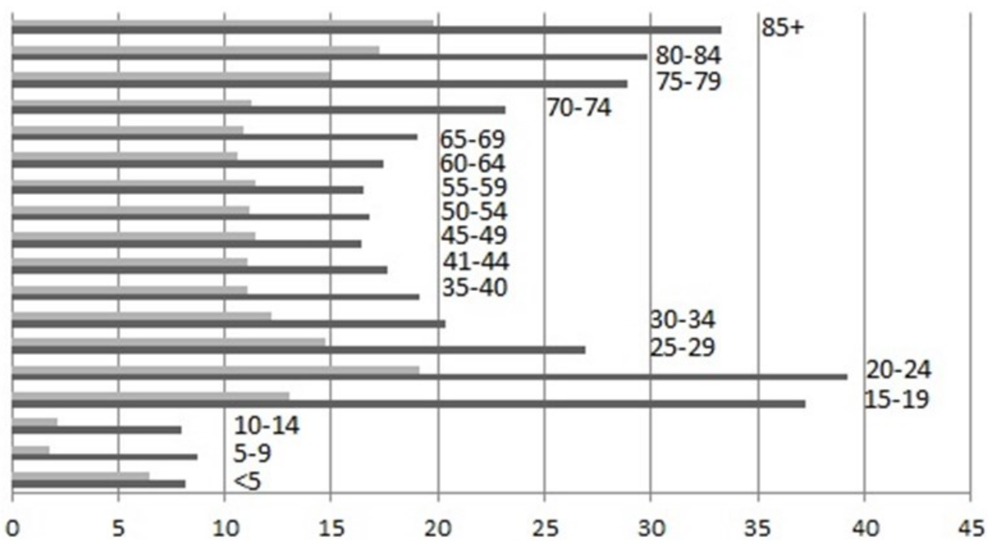

Figure 10-7. U.S. Road Deaths Per 100000 Population by Age Groups, 1975 and 2010

The least squares regression of miles driven per vehicle registered on temperature indicated 117 more miles driven per degree of increased temperature (F) in 2014, 137 in 2015, and 145 in 2016. When precipitation, unemployment, insurance costs, and gasoline prices were added to the equation they were not significantly related to miles driven per vehicle.

Table 10-3 shows the regression coefficients of these factors as predictors of the percent of 15-19-year-olds licensed in the years 2000, 2010, and 2015-2016. While each of the potential predictors seems to have an effect in one or more years, there is no obvious pattern related to recessions. Unemployment was below normal in 2000 and 2015-2016 but very high in 2010. Unemployment was related significantly and inversely to teen licensure only in 2015. Insurance expenditures were significantly related inversely to teen licensure in 2000, 2010, and 2016, the latter with a much lower coefficient. Gasoline prices were inversely related significantly to the percent licensure of teenagers in 2010. The differences in the coefficients in different years are not because of collinearity. The largest R^2 among the predictor variables was 0.16 between unemployment and insurance expenditures in 2010.

Table 10-3. . Least Squares Regression Coefficients of Percent of 15-19 Year-olds Licensed to Drive Related to Unemployment, Insurance Expenditures and Gasoline Prices in the Years 2000, 2010, and 2015-2016.

	2000	2010	2015	2016
Percent Unemployment	0.525	-.862	-4.364	-1.888
95% C.I.	-3.272,4.322	-1.028,2.752	-7.900,-.829	-5.83,2.06
Insurance Cost ($100)	-4.41	-4.00	-1.601	-1.97
95% C.I.	-6.955,-1.861	-6.382,-1.618	-5.30, .336	-3.43,-.50
Gasoline price per gallon	-29.71	-46.29	-17.577	-17.457
95% C.I.	-72.013,12.593	-80.791,-11.789	-36.019,0.866	-34.97,.061

Table 10-4. Predicted Road Deaths in 2015 If Each Predictor Variable Was Unchanged from 2014 and in 2016 if Each Predictor Variable Was Unchanged from 2015, Sum From Contiguous 48 U.S. States.

	2015			2016		
	Predicted	Diff.	%	Predicted	Diff.	%
Temperature	33047	1863	5.34	35860	1370	3.68
Precipitation	34950	-40	-0.11	36437	792	2.13
Unemployment	37409	-2499	-7.16	37800	-570	-1.53
Vehicles/Population	34961	-51	-0.15	36286	944	2.53
Percent Trucks	33661	1249	3.58	35622	1607	4.32
Percent Motorcycles	35022	-112	-0.032	36744	486	0
Percent Buses	35012	-102	-0.029	36895	425	1.14
Median Age	35039	-129	-0.37	36742	488	1.31
Population	35036	-126	-0.36	36741	489	1.31
Gasoline price	30498	4412	12.64	37567	-337	-0.91
Insurance Cost	35450	-540	-1.55	37408	-178	-0.48

Using the logistic regression equations in Table 10-2 for the years 2015 and 2016, I estimated the changes in deaths that would be expected in 2015 if each of the variables was unchanged from 2014 while the others changed and in 2016 if each of the variables was unchanged from 2015. For each state, the expected number of deaths in a given year is $1/(1+e^{-x})$, where x is the logistic regression equation, times the population (Selvin, 1991). For each of the predictor variables, I substituted the 2014 value in the equation leaving the others at the 2015 value for that year (or the 2015 value in the 2016 equation. The sum of the predicted deaths among the states shown in Table 10-4 was compared to the actual deaths to estimate the number of deaths that occurred related to the change in prevalence of a given risk factor corrected for the status of the others.

The average annual temperatures (F) among the states in this study were 51.1 in 2014, 53.1 in 2015, and 53.9 in 2016. About 5.3 percent more deaths than expected were related to increased temperatures in 2015 and 3.7 percent more in 2016. Reduced unemployment in 2015 was associated with more than 7.2 percent fewer predicted deaths than occurred in 2015 and 1.5 percent less in 2016. Increased percent trucks of all registered vehicles were related to 3.6 and 4.3 percent increases in deaths in 2015 and 2016 respectively. Reduced gasoline prices were associated with a 12.6 percent increase in deaths in 2015 but a 1 percent decrease in deaths in 2016. Deaths declined somewhat from expected related to increased insurance expenditures, 1.5 percent in 2015 and 0.5 percent in 2016.

These results support the hypothesis that increasing temperatures during 2015 and 2016 contributed substantially to the increase in road deaths in the U.S. The increase in miles driven per vehicle predicted by temperature supports the hypothesis that the association between deaths and temperature is the result of increased road use in warmer areas. The association of higher temperatures with motorcyclists’ and bicyclists' deaths suggests that increased use of the road by riders of these vehicles also occurred as average temperatures increased.

Except during economic recession and years immediately following, unemployment was associated with more road deaths per population, the opposite of that found in correlations of trends in unemployment and fatalities nationally. Correlating trends in unemployment, time trend, and deaths at the national level is misleading. The high correlation between linear trend and miles traveled suggests a valid model but the annual national variation in unemployment accounts for little of the variance which is primarily due to the trend in mileage which is partly a function of temperature. Variation of unemployment among states in almost any year is much larger than annual variation nationally in time. For example, when the national unemployment rate in 2010 peaked near 10 percent, 5 states had a rate of 6 percent or less. There is no such thing as a "U.S. Economy" just as there is no such thing as "national weather". Different sectors of the economy are prominent in various states affecting growth and attrition in different areas of the country at different times. The effect of recessions in particular states depends on the sector that gets out of control and other factors (Owyang, et al., 2003). Furthermore, the equation based on the national unemployment rate, vehicle miles traveled and the linear trend did not predict future deaths accurately.

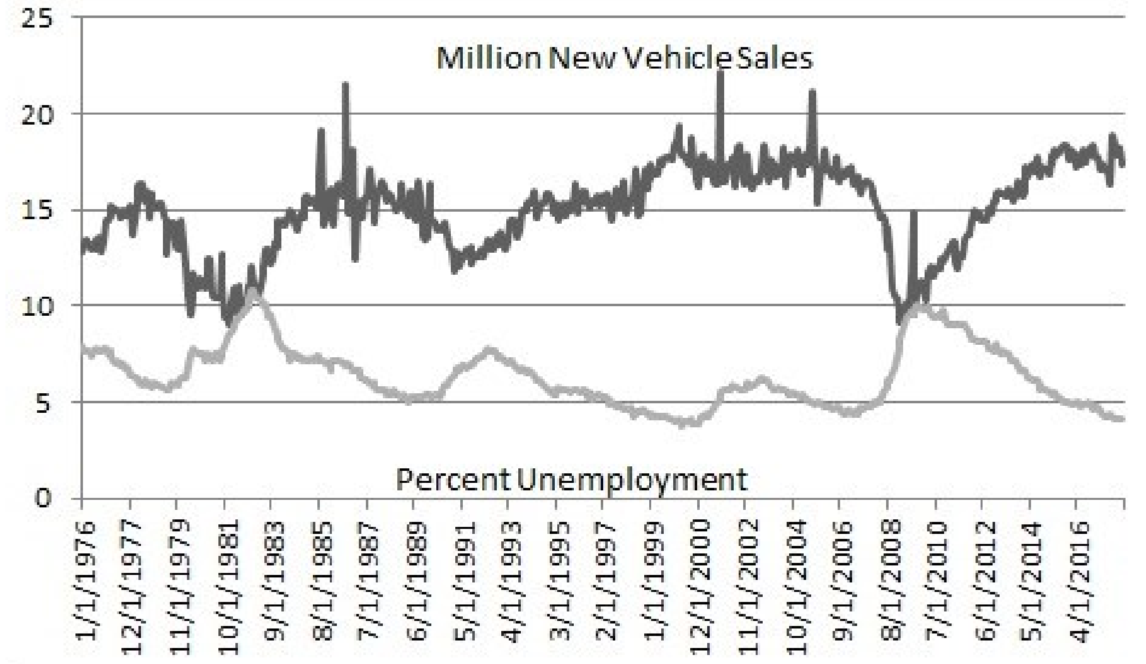

Figure 10-8. Annualized Monthly Sales of New Vehicles in the U.S. compared to Monthly Percent Unemployment, 1976-2018

Higher unemployment among states in this study predicted fewer deaths except during and following recessions, contrary to the national trend research. That research did not take into account climate, insurance costs, gasoline prices, and the mix of vehicles other than commercial trucks in one state-level study (He, 2016) or the number of vehicles per population. I have found no study that compared the involvement of the employed and unemployed as drivers in crashes. The unemployed could drive more in job seeking and other activities for which they have more time or less because they cannot afford fuel. The unemployment rate related to fatalities among the states is a proxy for relative economic conditions. During economic recessions, reduced teenaged licensure, commercial traffic, and commuting may contribute to reduced deaths offsetting the adverse effect of the reduced sale of new, safer vehicles. Light vehicles sold in the years 2011 and afterward are required to have electronic stability control that reduced road death risk by about 42 percent in vehicles that had the technology earlier compared to those that did not (Robertson, 2007). Crash avoidance technologies such as lane deviation detection have also been installed in various vehicle models. Reduced fatalities related to lower unemployment during 2015-2016 were likely due to relatively more frequent purchases of new safer vehicles in the more prosperous states. I was unable to obtain data on new vehicle registrations among the states to measure the degree of confirmation of that idea but nationally new vehicle sales vary inversely with the unemployment rate (Figure 10-8). The correlation of lower unemployment with reduced deaths in 2015 is particularly remarkable given that higher unemployment rates were associated with reduced teenaged licensure in that year.

This study does not support the hypothesis that vehicle insurance increases overall death risk. Contrary to the hypothesis, road deaths per population are consistently lower when insurance expenditures are higher, at least partly related to a reduction in the licensure of teenagers to drive

The magnitude of the 2015-2016 temperature increase was unusual for two years but few scientists question the evidence that indicates continued warming of the atmosphere for the foreseeable future from the combustion of fossil fuels (Solomon, et al, 2009). The evaporative effect of warming oceans increases precipitation but where and when it will fall is difficult to predict (Trenberth, 2011). Since increased vehicle miles result in increased CO_2 emissions, the effect of temperature on miles driven suggests a classic feedback system – more miles - more CO_2 - more warming - more miles.

References – Chapter 10

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