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SPECIAL FEATURE: MASS TRANSIT

Health and Safety Hazards Associated with Subways: A Review

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ABSTRACT *Subway systems are key components in mass transportation networks worldwide, providing rapid and affordable transportation to urban communities in 58 different countries. The benefits afforded by subway transit are numerous and mainly derived from the reduction in automobile use, thereby limiting environmental and health hazards associated with exhaust-air emissions. Additionally, by limiting congestion and providing vital transportation links within a city, subways also improve the overall quality of life of urban communities. However, to best maximize the positive impact on the urban environment, subway systems need to provide a safe and healthy environment for both passengers and subway transit workers. Periodically, safety concerns are raised, most recently in relation to the vulnerability of subways to terrorist attacks. To examine this issue more carefully, we conducted a structured review of the literature to identify and characterize potential health and safety hazards associated with subways. A secondary goal was to identify various risk management strategies designed to minimize the risk of these hazards. This information may be helpful to urban communities, urban planners, public health specialists, and others interested in subway safety.*

KEYWORDS *Mass Transit, Safety and Health, Subway Riders, Subway Transportation, Transit Workers.*

INTRODUCTION

The US mass transportation network relies heavily on rail systems, two of which are particularly important in the urban setting: subways and commuter rail systems. Subways, also referred to as metro, heavy rail, or rapid rail, operate, for the most part, within a metropolitan area, whereas commuter rail systems (also known as suburban or regional rail) operate between a city and the outlying suburbs.[1] Both have a long history tied to the development of urban centers. In the United States, for example, explosive urban population growth in the 1880s led to the development of the first US subway system, which was constructed in Boston in 1897, soon followed, in 1904, by the first New York City subway line.[2] There are now 14 different subway transit system agencies in the United States providing service to 11 different metropolitan areas, with a new system planned for Puerto Rico.[3]

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Worldwide, there are 95 subway systems in operation, providing service to vast numbers of riders; seven of the systems report over 1 billion passenger rides each year.[4] New York City (NYC) Transit, the largest subway system in the United States, with 7 million passengers each weekday and over 1.3 billion rides a year, is surpassed in volume by several other major subway systems, including Moscow (the largest at 3.2 billion rides per year), Tokyo with 2.6 billion, and Seoul and Mexico City, each with 1.4 billion rides per year.[4–6]

The ability to sustain ridership at these volumes is dependent not only on extremely complex subway system infrastructures, but to a great extent on other important supporting systems, such as reliable energy supplies.[7] By virtue of both the level of their complexity and dependency on external forces, subway systems are vulnerable to any number of natural (e.g., severe weather) and man-made (whether accidental or purposeful) hazards. Besides these vulnerabilities, subways may also be associated with a range of health and safety hazards that could affect both passengers and transit workers; these include physical (e.g., noise, vibration, accidents, electrified sources, temperature extremes), biological (e.g., transmission of infectious diseases, either through person-to-person spread or vector-borne, for example, through rodents), chemical (e.g., exposure to toxic and irritant chemicals and metals, gas emissions, fumes), electro-magnetic radiation, and psychosocial (e.g., violence, psychosocial workstress) health hazards. Today, another type of subway hazard we need to consider is the threat of terrorism, which could take the form of a mass casualty event (e.g., resulting from conventional incendiary devices), radiological attack (e.g., dirty bomb), chemical terrorist attack (e.g., sarin gas), or bioterrorist attack (e.g., weapons grade anthrax).

To examine these issues more closely, we conducted a structured review of the literature.

METHODS

A computerized search of government documents as well as the peer-reviewed literature for relevant articles addressing subway safety from either the mass transit or passenger perspective was conducted. The search was limited to articles published in the English language since 1970. The search strategy included identifying keywords ("subways," "health," "safety," "transit workers," and "passengers") and searching suitable databases (Medline, Ovid, Embase, Cochrane Database of Systematic Review, HealthStar, and CINAHL). Also, we conducted more general searches of the World Wide Web by using the Google search engine.

RESULTS

On the basis of the results of the search, the following hazards associated with subways were chosen for review here: general safety (e.g., injuries), violence, and noise. Each of these is briefly discussed below, followed by a miscellaneous section that addresses other less commonly reported health and safety hazards potentially associated with subways.

General Safety

The subway environment, with its enormous volume of people navigating heavily congested pathways, constricted platforms, and crowded stairs, escalators, elevators, ramps, and transfer stations, provides numerous opportunities for adverse incidents to occur. Despite these challenges, the actual number of subway-related injuries reported by the US Federal Transit Authority, roughly 10,000 each year, is remarkably low.[8] Specific data with respect to the type and cause of these injuries are lacking, but appear to be mainly related to slips, trips, and falls experienced by passengers.

Subway-related, nonviolent-fatal accidents are fortunately relatively few in number. With an average of 20–60 passenger deaths each year, the rate of subway-associated fatalities is much lower than the fatality rate associated with automobile travel (0.15 vs. 0.87 per 100 million passenger miles).[9–11] In fact, cities with high subway ridership rates have a 36% lower per capita rate of transportation-related fatalities than low ridership cities (7.5 vs. 11.7 annual deaths per 100,000 residents).[12] Excluding automobile fatalities, subways however, have higher (all causes) fatality rates than other forms of mass transit, as shown in Table below.

Injury data specific to subway workers, an estimated workforce of 350,000 people, are difficult to assess, because the Bureau of Labor Statistics includes these workers with other inner city transport employees (excluding bus drivers). However, available data suggest that subway workers may be at an increased risk of workplace injuries compared to other workers.[14] In 2002, the rate of injury for inner city transport workers, at 7.9 per 100 employees, was higher than the average US occupational injury rate (5.3 per 100 workers) and actually higher than rates for high hazard jobs, such as coal mining (at 6.8 per 100 workers) and heavy construction (at 6.4 per 100 workers).[14] Fatalities are, however, rare, with 3–5 accidental subway worker deaths recorded each year, although some underreporting might occur.[15]

Reductions in subway-related injuries for both passengers and workers may be realized through the application of sound safety management practices, the details of which are outside the scope of this review. However, the assessment of accident rates on a per capita basis across systems with varying safety programs, as well as within systems, both before and after the implementation of new safety initiatives, would undoubtedly inform risk reduction practices. Unfortunately this type of information is not readily available. Research in this area would therefore be helpful in identifying particularly effective risk reduction strategies that are tailored to the subway environment.

Security and Violence

Policing subway transit is a challenge. At rush hours, large numbers of people are brought together under potentially volatile conditions, that is, confined, overcrowded spaces that are often both overheated and noisy. Conversely, during off-peak hours, there may be relatively few people on the subways. Both conditions can provide a climate for crime. The structural environment of subway systems may also present opportunities for security incidents and violence to occur; these include numerous unobserved niches and empty spaces, and sprawling, often unmanned

TABLE. Fatality rates by mode of travel, 1998–2000

Type of vehicle	Mortality rate
Heavy rail (subways)	0.15
Automobiles	0.87
Intercity and commuter railroads	0.06
Transit buses	0.05
Intercity buses	0.04

Average deaths per 100 million passenger miles.[10,11,13] and poorly lit stations. These conditions can support crime, even if the station is not located in a particularly high-crime area of a city.

In addition to providing a climate for crime, subways may also provide a climate for the fear of crime. Highly sensationalized subway crime reports in the media may result in misperceptions regarding the actual risk of crime, and resultant fear can drive down ridership rates, leading to desolated subways cars and platforms, further supporting crime. However, despite the potential risk factors and perceptions about subway crime, data indicate that crime in subways is relatively infrequent, especially when considering the volume and potential risks inherent to the subway environment.

Nonviolent Crime Data on nonviolent crimes committed on subways may be an underestimation of the true number of incidents, because these types of crimes (e.g., fare-evasion and vandalism) are generally only reported if an arrest is made. In 2001, the number of nonviolent-crime arrests on US subways were as follows: disorderly conduct (27,626), fare evasion (24,852), loitering (2,396), drug use (2,015), trespassing (1,228), drunkenness (1,308), and vandalism (984).[16] Vandalism, although relatively low and generally decreasing in occurrence, cost US subway transit systems millions of dollars in property damage.[16] Nonviolent crimes involving theft were also reported, including pickpocketing, purse snatching, etc.; in 2001, there were approximately 6500 passenger thefts and 125 employee thefts.[16]

Violent Crime Overall, there are about 12,000 violent subway-related security incidents reported in the US each year, including cases of homicide, rape, larceny, aggravated assault, and arson.[16] Although, the number of reported violent crime incidents on subways is much higher than other forms of mass transit, it is relatively stable and reflects the much larger ridership levels of subways compared to these other forms of transit.[16,17] With respect to national violent-crime trends, in 2002, 5 million such violent incidents were reported by the Bureau of Justice Statistics, but only a small fraction (1%) of these crimes occurred on public transportation (all forms).[14] For example, of approximately 250,000 rapes occurring in the United States in 2002, 1.2%, (about 3000) were associated with mass transit (all forms).[18,19] Likewise, of 16,000 homicides that occur in the United States each year, 0.013% (n=20) are subway-related.[17,18]

More detailed crime statistics data are provided by some individual transit agencies. For example, NYC Transit reported that in the first 6 months of 2004; there were 873 cases of grand larceny/pickpocket/wallet stealing/chain snatching, 530 robberies, 144 assaults, 5 burglaries/break and entry, 1 rape, and 2 murders.[19] The overall NYC subway crime rate in that time period was 10% lower than the rate for the same period in the previous year, with an average of 8.6 major felonies–nearly the same as the prior year's average of 8.5.[19] Crime on the NYC subways has been steadily declining, reflecting overall declines in crime citywide. For instance, there were 26 subway-related murders in 1990, 4 in 2003, and 2 in the first 6 months of 2004.[19] These findings are supported by data from the NYC medical examiners office, which document declines in mass transit (all forms) related fatalities (both violent and nonviolent); the total number of fatalities decreased from 126 in 1990 to 53 in 1998 (S. Galea, personal communication).

Comparison of crime statistics data between subway systems are difficult to make, not only because rates on a per capita basis (i.e., by ridership) are often not available, but also because certain factors, such as hours of operation, can affect crime rates.

Subway Specific Events

Two categories of violent crimes uniquely associated with subways deserve special attention; these are pushing and attempted pushing onto the tracks and subway suicides.

Pushing or Attempted Pushing onto Tracks This is an especially frightening form of violence; a survey conducted in 1992 found that 77% of randomly selected NYC passengers were afraid of being pushed onto the tracks, and 80% took specific protective actions to avoid this from happening.[20] Fortunately, this type of violent event is rare. A study by Martell and Dietz involving violent offenders who pushed or attempted to push people onto NYC subway lines found that between 1975 and 1991 there were 49 incidents involving 52 victims, all strangers to the perpetrators.[21] During that time, the annual average ridership was in excess of several million passengers each day.[6] Most of the perpetrators of this type of subway crime are mentally ill, homeless people, with long histories of psychiatric hospitalizations and prior arrests.[21]

Subway Suicides Another type of violent event that is also uniquely associated with subways, is attempted or completed suicide by throwing oneself onto the electrified track and/or into the path of oncoming trains. A review of Montreal coroner's office data from 1986 to 1996 noted 129 suicides in the Montreal Metro, with one out of every three suicide attempts resulting in fatalities.[22] Most of the victims chose stations closest to their place of residence, the majority were men (61%), 64% were younger than 40 years of age, and most (76%) were single.[22] Alcohol was found in 25% of the victims' blood analyses, although the levels were generally not very high.[22] Many (73%) of the victims had serious mental health problems; for the cases for which information was available, previous suicidal ideation was very common, as was previous suicide attempts and a history of in-patient psychiatric care.[22]

A review of suicide data from 23 different subway systems worldwide found that suicide attempts and completions occur in almost all systems, with the percentage of attempters who died varying from 20 to 70%, with the variance related to the operation and features of the subways.[23] For example, subway systems with "suicide pits" (areas around suspended rails that allow people to lie beneath passing trains) have much lower death rates among suicide attempters (45% compared to 66%) than systems without such features.[23] Subway systems with physical barriers in place to limit passenger access to tracks, such as the subway system in Singapore, do not report any subway suicides.[22] Subway suicide rates also seem to be related to more complex social factors; in Vienna, after local newspapers were convinced to stop printing stories of subway suicide victims, the rates fell by 75%.[24]

Approaches to Reduce Violence on Subways Mass transit policing relies on many of the same techniques found to be effective in reducing crime in general, such as "situational crime prevention" and "community-policing."[25] These techniques serve to increase the degree of difficulty in committing a crime, while at the same time limiting the rewards and incentives of crime.[26] Increasing the visibility of police and lowering the level of disorder on subways, by limiting disorderly conduct (e.g., graffiti, aggressive panhandling, loud boom boxes, public drunkenness, etc.), reduces the climate for crime, as well as the fear of crime. Additionally, various aspects of the subway environment can be managed to reduce crime, such as using graffiti-resistant materials and limiting access to unmanned areas, such as public restrooms.

Strategically placed closed-circuit television cameras and improved communication systems may also serve to deter crime. As with nonviolent incidents, comparisons of data on violent crimes between subway systems and the effectiveness of different approaches to transit policing are difficult to assess because of limited available data. However, as shown by the NYC Metropolitan Transit Authority (MTA) data, extensive and wide ranging crime prevention programs can result in significant reductions in subway crime rates.

Noise

The issue of noise and noise pollution periodically surfaces as a concern in urban settings. For example, in New York City, legislation was recently proposed that would substantially update the existing 30 years old NYC Noise Code, driven in part by more than 1,000 noise-related complaint calls made each day.[27] Support for the revised code is broad and based upon the consensus that excessive noise adversely affects the quality of life of city dwellers. Importantly, excessive noise [i.e., exceeding 85–90 decibels (dB)] for extended periods of time, for example, 8 hours per day over the course of several years, can result in noise-induced hearing loss (NIHL), a serious medical condition affecting over 10 million Americans.[28] Hearing loss related to noise is highly individual and can even result from much shorter exposure periods, especially when the sound levels far exceed 90 dB. Importantly, NIHL is the single most-common health problem in workers in industrial societies.[29]

Subways present a special concern with respect to noise, as many subway systems, especially older systems, are obviously noisy environments. This is not only because of the many processes involved in rail transit, but also because noise is amplified in the enclosed space of the underground subway. Therefore, both passengers and subway workers may be at risk of exposure, and because of the time spent on the job, presumably workers would be at a greater risk for subway-related NIHL compared with passengers. In addition to causing impaired hearing, excessive noise can also adversely affect general health as well.[30,31] In the workplace, excessive noise exposure has been shown to affect quality of worklife, lost worktime, perceived workstress, and job dissatisfaction.[32–34]

However, the extent to which hearing loss is actually related to noise exposure, such as subway noise, is difficult to ascertain, because hearing loss is due to many other well-characterized factors as well, such as age, with increased loss in hearing becoming more pronounced after age 50[35] and gender, with males generally tending to have poorer hearing than females.[35] Another important factor to consider with respect to NIHL is the contribution of nonwork-related noise exposures, such as noise associated with military service, fire arm use, motorcycling, amplified music, boating, and use of power tools.[36]

The question of whether subways are associated with excessive exposure to noise is also difficult to assess, because data on this topic are particularly sparse. Data from a 1971 study of NYC subways noted noise levels on specific train lines ranging from 75 to 110 dB, both at the platform level and inside cars.[37] In comparison, a whisper is 30 dB, normal conversation is 45–60 dB, chainsaw noise is 100 dB, and a gun blast is 140 dB.[38] Results from the study noted that certain subway cars, especially those manufactured prior to 1970, had higher noise levels than newer cars, and that certain subway workers were at particularly high risk, such as operators and conductors, with their rates calculated at 93–110 dB for 6–8 hours per day.[37] Trackmen, token booth operators, and structural, power, and lighting specialists were also at risk.[37]

To assess current levels of NYC subway noise, we recently collected pilot data by using a digital sound level meter (R. Gershon, unpublished data) and found that noise levels on platforms and inside cars ranged from 56 to 97 dB, with the highest levels occurring when trains braked as they entered stations and when express trains passed local stops.

Although these more recent data indicate that noise levels on subways can reach excessively high levels, we know of no published reports on hearing assessments of subway workers or passengers. However, data are available from a large study of railroad workers on above-ground (surface) railroads. Audiometric testing of nearly 10,000 freight trainmen, engineers, conductors, brakemen, and firemen found that trainmen who used no guns and were free of nosocusis (hearing loss caused by factors other than noise and aging) had a 12- to 22 dB-depressed hearing sensitivity at higher frequencies [e.g., 3,000–6,000 hertz (Hz)] compared to non-exposed men matched by age; by age 50, 60% of the railroad noise-exposed subjects without non-work risk factors had NIHL.[39]

Risk Management Strategies to Control the Risk of NIHL In the United States, the Occupational Safety and Administration regulates noise exposure in the workplace and has set a permissible exposure level of 85 dB per 8-hour time weighted average.[40] For impulsive noise (sudden spike of high noise), the accepted limit is 140 dB.[41] The risk of noise exposure in the workplace is managed by following a standard hierarchy of risk management controls, including engineering, administrative, regulatory, medical, and personal protection controls. Although most of these controls are designed for workers, the use of personal hearing protection devices (PHPD) (e.g., earplugs, ear muffs) can help reduce exposure for passengers; noise canceling head phones can reduce sound levels by 10–25 dB, properly fitted PHPD can reduce the noise by 15–30 dB, ordinary cotton or tissue are poor protectors and reduce noise by 7 dB, whereas placing fingers in ears reduces the noise by only 5 dB.[38,39]

There are many other noise reduction strategies that have been shown to reduce subway noise levels, such as improved wheel maintenance, the use of rubber wheels, seamless (not jointed) welded rails, antilock braking systems, and the use of noise dampening and noise absorption systems. However, comparison of noise levels across systems that have instituted noise prevention (i.e., newer subway systems) or noise mitigation (antilock brakes) practices have not, to our knowledge, been published, and the extent to which these changes have affected the hearing of both workers and passengers is unknown. Research in this area would help address important knowledge gaps.

Miscellaneous Health and Safety Hazards Associated with Subways

There are many other potential subway-related health and safety hazards for which data are extremely limited. This includes whole-body vibration, which has been linked to self-reported back pain among subway operators; excessive exposure to heat; psychosocial stress, in both workers and passengers; and most recently, poor air quality.[42–46]

The subject of air quality, which is addressed by Chillrud et al. in this issue,[47] is especially of concern because millions of subway passengers may be exposed to potentially dangerous pollutants. Although data are new and somewhat limited in this area, elevated metal levels, believed to result from the friction of wheels (made of steel) on steel rails, have been documented for many subway systems. In one study of the Helsinki Metro, particles less than 2.5 μm in mean mass diameter collected on filters contained very high concentrations of certain metals such as iron, manganese, copper, chromium, and nickel.[48] Similarly, increased levels of these metals in subway systems have been reported in other studies as well and are a concern because of the health risks associated with excessive exposure.[49,50] Although research in this area is growing, clearly more work is needed, especially given the large number of potentially exposed individuals.

Another potential health hazard related to subways is the transmission of infectious diseases communicable through close person-to-person spread, or indirectly, through contact with a contaminated fomite (inanimate object). Although it is not inconceivable that both respiratory and gastrointestinal pathogens could be spread this way, this has not been documented. Similarly, transmission of various diseases of the skin and hair [e.g., tinea capitis, ringworm of the scalp, and head and body lice (*Pediculus humanus*)] may also occur, either through direct contact with infected persons, or indirectly through contact with contaminated objects (e.g., seat backs, clothing).[51] Again, this has been not documented to occur. Because rats may be a problem in some subway systems, it is important to consider diseases that may be spread by these rodents. In particular, *Streptobacillus moniformis* (rat bite fever), although uncommon in North and South America and most European nations, is a concern because it can be readily spread from infected rats to human through rat bites,[51] which have been anecdotally reported to occur on subways.

Prevention of disease transmission includes maintenance of ventilation systems to lessen the likelihood of respiratory transmission of diseases and adequate sanitation of the system, including periodic disinfection of subway surfaces for other types of pathogens. At the individual level, hand hygiene is important, including hand washing after leaving the subway and being careful to keep hands away from eyes and mouth during the trip. Control of rats is essential.

Another potential subway hazard also increasingly being considered is electromagnetic field (EMF) radiation. This is a concern not only because there are numerous sources of EMF associated with subways, but because measurements indicate that exposure levels, especially among subway workers, approach, and in some cases exceed, guideline levels.[52] Although the health effects of exposure to EMF are mixed, researchers have suggested that present standards and guidelines do not adequately address the complex subway transit environment, and thus additional research in this area is warranted.[53,54]

Finally, terrorist threats or attacks on subways also present the potential for harm. This is a concern because the vulnerability of subways to such attacks is well established;[55] the physical structure, large volume of people, and degree of impact on the immediate and surrounding communities make subways a plausible target for such attacks. These same factors also create challenges for both terrorism preparedness and response, including evacuation. Strategies to address this issue are too numerous to detail here, but in general include development and implementation of risk assessment and surveillance systems, effective communication systems, and emergency preparedness, including readiness training of subway workers.[56,57]

DISCUSSION

Subways are an integral component to mass transit and play an important part in maintaining the livability and sustainability of the urban environment. Although many potential vulnerabilities and operational characteristics of subways present challenges and potential risks to passengers as well as subway workers, we often ignore these as our reliance on subways is so great. However, rapid growth of urban environments with even greater numbers of citizens relying on mass transit, including subways, may further strain already overburdened and aging subway systems, potentially increasing health and safety hazards. It is clear these and other issues, such as the threat of terrorism, will need to be addressed if we are to be fully reliant on subways as an important mode of transportation in the urban setting.

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