

THE INJURY RISK TO WHEELCHAIR OCCUPANTS USING MOTOR VEHICLE TRANSPORTATION

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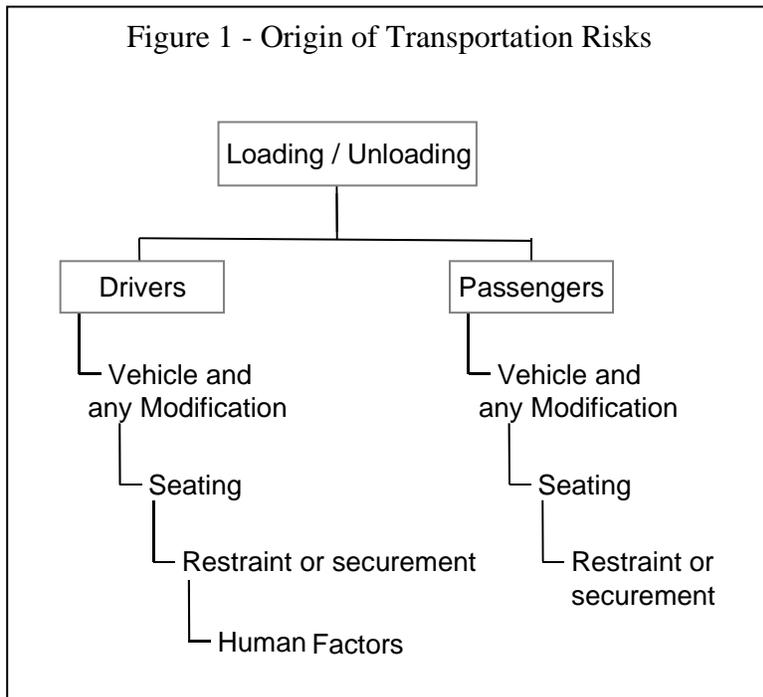
ABSTRACT

The transportation safety experience for persons using wheelchairs is largely unknown. Motor vehicle crash involvement and injury frequency was examined in a telephone interview completed by 596 wheelchair users. Overall, 42% were drivers. Most subjects also rode as passengers in private vehicles (87%) and public vehicles (61%). Wheelchair use as a seat in the vehicle was higher among passengers than drivers. Crash involvement was highest among drivers and lower in passengers. Reported injuries from non-crash scenarios, though, were higher in passengers compared to drivers. Persons seated in wheelchairs in vehicles appear to be at a greater safety risk.

Recent legislation and regulatory changes have enhanced the access to and use of public and private motor vehicles by persons with disabilities, including up to 1.7 million persons in wheelchairs [Kaye, Kang, LaPlante, 2000]. At this time, it is not known what level of safety risk might be associated with these new opportunities. There

is some concern that safety for the wheelchair user may be compromised. For example, many individuals do not transfer to motor vehicle seats and travel while seated in their wheelchairs. Several federal regulations (FMVSS 201, 207, 208) exist to protect occupants seated in vehicle seats. However, there are no federally mandated regulations that address wheelchairs used as seats in vehicles. Indeed, the features that make the wheelchair a good mobility aid often make it a poor vehicle seat.

BACKGROUND - Several factors may influence the injury risk of persons using wheelchairs in private or public transportation settings. These factors are outlined in Figure 1. In a typical scenario, the first concern is getting into or out of the vehicle. Persons in wheelchairs have various forms of functional disability, which, in turn, affects their ability to use vehicle seats. Individuals with higher levels of physical functioning are often able to move themselves from the wheelchair into a vehicle seat. Several individuals, though,



do not have this capacity. For these individuals, the vehicle must be modified to allow for wheelchair access into the vehicle [Cooper, 1995]. The most common modification in this regard is the addition of a platform or crane lift. These devices provide a large flat surface approximately the size of the wheelchair that allows the user roll or drive the wheelchair onto the surface. This platform then ascends or descends between the ground and the vehicle's floor. With respect to injuries, several anecdotal reports note accidents while loading or unloading, such as the wheelchair falling off of the platform surface.

Vehicles are also modified to provide space for chair access and maneuverability. Additional space is necessary to prevent the contact of the individual (who is using the wheelchair as a seat in the vehicle) with other vehicle structures in the event of a crash. Another typical modification is the installment of a wheelchair securement system (also known as tie-downs). Securement systems are necessary to stabilize the wheelchair while it is parked in the motor vehicle. Engineering standards have been developed for these wheelchair tiedown and occupant restraint systems, also known as WTORS (ISO 10542).

Three primary issues affect the safety of individuals seated in wheelchairs in motor vehicles. First, there must be compatibility between the wheelchair, the occupant restraint, and the tiedown technology [Cooper, 1998]. Second, restraints and tiedown systems must be used properly to prevent the chair from moving or tipping over or to prevent the person from falling out of the chair. These adverse scenarios may originate in crashes or in situations where the vehicle has extreme maneuvering, such as sudden braking, sharp turns, or rapid acceleration.

Third, the wheelchair should be suitable for occupant seating during motor vehicle transportation. The ISO 7176-19 engineering standard currently addresses design, performance, and testing methods for wheelchairs that are intended for use in motor vehicles. However, the major injury-related concern is that many wheelchairs in use today do not meet these standards. Also, individuals may be involved in crash scenarios (such as rear or side impact) that are not addressed by this standard.

QUANTIFYING TRANSPORTATION RISKS - At present, research to quantify the transportation risks faced by wheelchair occupants in motor vehicles is very incomplete. Preliminary reports characterize a variety of injuries to wheelchair users in transportation-related activities. A review of the incidents involving wheelchairs in the National Electronic Injury Surveillance System (NEISS) database from 1991-95 reported that an estimated 60,000 persons in wheelchairs are injured per year [NHTSA, 1997]. Of this figure, 2%, or 1500 events, involved motor vehicles. These injuries were due largely to improper or non-securement of the wheelchair (35% of the total injuries identified), lift malfunctions (19%) and collisions between the wheelchair and the motor vehicle (26%). Nearly all of the injuries identified in this report occurred while the motor vehicle was stationary.

Two other reports [Richardson, 1991, Shaw, 2000] identified fatalities and injuries to wheelchair users in moving vehicles. Both reports were also based upon NEISS data. Richardson (1991) estimated that there were about 2200 injuries among wheelchair users in motor vehicles from 1986-1990. Most of the injuries were attributed to improper securement in vans and buses during sudden stops or sharp turns. Shaw (2000) found 33 injury events related to motor vehicle accidents from 1988-1996. This figure projects to about 1320 incidents nationwide.

The limited information available on the transportation risks in this population arises, in part, from methodological issues that reduce the ability to identify or distinguish wheelchair users from the general population. Table 1 outlines these issues as they apply to the data sources used in most existing crash and injury surveillance systems. For example, many of the best-known data sources for studies on motor vehicle-related injuries (medical records and police accident reports) do not provide adequate information to identify wheelchair users. Medical records rarely note if a person uses a wheelchair or not. The NEISS data only capture this information because the chair is regarded as a consumer product. Most police accident reports do not document wheelchair use as a data field.

Police accident reports provide a good description of several risk variables in this population. They distinguish drivers from passengers, identify the vehicles involved, and for fatal crashes, at least, have valuable information on restraint/securement use. However, these reports also miss large categories of transportation injuries to wheelchair users. Particularly so with respect to injuries on non-public roads, those related to loading and unloading, and those occurring in situations where the vehicle does not crash. Transit system records are another potential source to identify injuries. These records, though, only describe events related to public transportation (ignoring private transportation risks) and are not routinely available for research purposes.

The small size of the wheelchair using population may also limit the applicability of mainstream surveillance systems for investigations into this topic. The NEISS data described previously [Richardson, 1991, Shaw, 2000] were based upon 30-50 events over a multiple year period. Our review of the Impair File in the General Estimates System data for 2002 found only 15 crashes involving a driver with paraplegia or one restricted to a wheelchair. Further, we conducted a brief survey of analysts in the Fatality Analysis Reporting System (FARS) and identified only 6 wheelchair users involved in fatal crashes over a two-year period.

Table 1: Potential Data Sources for Examining Transportation Risk in Wheelchair Users

Crash Data Source	Identifies Wheelchair Occupants	Identifies Vehicle Involved	Identifies Securement of the Wheelchair	Implications
Medical records	Only in limited applications, such as NEISS	No	Generally no	a. rarely identifies wheelchair users b. very limited vehicle/securement data
Police accident reports, including FARS data	Generally no	Yes	Generally unreliable	a. not all crashes have police reports b. poor ascertainment of wheelchair use and securement in non-fatal crashes c. does not include loading/unloading and non-crash related injuries
Surveys	Yes	If assessed	If assessed	a. subject to recall bias or under-reporting b. subject to measurement error
Transit system records	In limited applications	Yes	Limited recording	a. records are not generally accessible b. no data on private transportation c. small sample sizes

Given these limitations, one could argue that the most appropriate study design to use for studies of motor vehicle injury risk in wheelchair occupants is one based upon surveys or personal interviews of the population using wheelchairs. This design allows an investigator to identify exposure to various forms of transportation, typical seating configurations, and past experience pertaining to accidents and injuries. Surveys, though, may be influenced by the respondent and their ability to remember or willingness to provide information on crashes or injury incidents.

Thus, existing data to document the level of risk associated with wheelchair transportation are extremely limited. The importance of issues such as the type of vehicle used, (car, van, paratransit, public transport, etc.), the type of seating used, the mode of transportation use (driver or passenger), and the influence of differing types of disability, have not yet been fully addressed.

OBJECTIVE – In this light, the following report seeks to begin an investigation into the transportation risks faced by wheelchair users. We surveyed a large cohort of wheelchair users to identify their frequency of involvement in a) motor vehicle crashes, and b) non-crash situations that resulted in an injury. We also examined if these events differed by public or private transportation use, and among persons seated in wheelchairs or vehicle seats in the vehicle.

METHODS

This report is a cross-sectional study of the transportation experiences noted by individuals who use wheelchairs. The primary eligibility criterion was that subjects had to use a wheelchair as their primary means for mobility. Thereafter, we sought to identify participants for this study who would represent the traits of wheelchair users. For example, individuals may have become disabled from many types of medical conditions, including spinal cord injury, cerebral palsy, stroke, and multiple sclerosis. We also sought to consider transportation scenarios in the young and the old.

A nationwide recruitment strategy was conducted to identify participants. Advertisements for the study were distributed through several national disability groups and their state-based affiliates. Rehabilitation hospitals and Centers for Independent Living were contacted, as were the state-based disability councils and Americans with Disabilities (ADA) Coordinators. We also advertised the study

through several disability-focused Internet Message Boards and online newsletters. Overall, 117 distinct groups were contacted.

Participants interested in the study were given a survey by telephone to verify eligibility and to identify transportation use and experiences. Survey responses were collected from June 2002-November 2003. Survey questions examined the manner in which the participants used transportation (as a driver and/or passenger), the type (public and/or private vehicle) and frequency of use (miles/week), and the type of seating typically used while in transport (vehicle seat or wheelchair). Participants were asked to recall the number of crashes they were involved in during the previous three years.

Information on the frequency of injuries arising from non-crash situations in the past three years was also obtained. Non-crash events were defined as situations where the individual was in the vehicle and the vehicle did not crash into another vehicle or object. It includes examples such as quick or sudden braking, sudden or sharp turning, and quick acceleration. These scenarios pose a hazard to the wheelchair user who is not properly restrained and/or the wheelchair is not properly secured to the vehicle.

STATISTICAL ANALYSIS - The survey data were first examined to identify the demographic characteristics (age, gender, type of disability, length of time using a wheelchair, and the type of wheelchair used) of the respondents. We then examined the transportation risk to wheelchair users from two perspectives; wheelchair users as drivers, and as passengers. This approach was taken because the safety messages arising from the study may differ by type of use. Passengers were further categorized to consider the type of vehicle involved (private or public).

Within each category of vehicle use (driver or passenger) and type (public or private), frequency distributions and rates were identified for the remaining transportation, crash, and injury variables. Factors related to reported crashes and injuries were examined next. In this analysis, the crash variable was dichotomized to categorize individuals as either reporting a crash or not. The injury variable was treated in a similar fashion. Reported crashes and injuries were then assessed relative to age group (0-18 years, 19-44, 45-64, 65+ years), gender, and seating type (seated in vehicle seat or in wheelchair). Chi-square statistics were used to test these relationships. Crash and injury rates (number of events per mile driven/traveled) were also examined by seating type using the t-test statistic.

RESULTS

PARTICIPATION - Overall, 596 subjects met the eligibility criteria as individuals dependent upon wheelchairs for mobility. Participants were identified from 45 of the 50 states. The majority of subjects were residents of California (10.8%), Florida (9.1%), and Pennsylvania (8.4%). Three percent of the study population were residents of Canada.

Table 2 outlines the demographic characteristics of the respondents. The sample was evenly split by gender. The average age of the group was 45.2 ± 14.0 years. A large percentage, 56%, were power chair users and the average duration of use of a wheelchair was 16.9 ± 12.8 years. The distribution of medical conditions leading to disability included one-third related to spinal cord injury, and another 28% reporting either cerebral palsy or multiple sclerosis.

Table 2 - Demographic Characteristics of Participants (n = 596)

	%
Gender	
male	49.6
female	50.4
Wheelchair Type	
manual	39.2
power	56.4
scooter	4.4
Age	
0-18 yrs.	5.0
19-34 yrs.	17.0
35-49 yrs.	34.0
50-64 yrs.	36.0
65 + yrs.	8.0
Disability	
Spinal Cord Injury	33.0
Cerebral Palsy	15.0
Multiple Sclerosis	13.0
Polio/Post Polio	8.0
Muscular Dystrophy	7.0
Spina Bifida	5.0
CVA/Neurological	5.0
Other	13.0

USE OF TRANSPORTATION - In this study, the respondents reported a strong use of motor vehicle transportation. They typically left their homes an average of 5 ± 2 days per week. Only 5.4% rarely traveled outside of their home (1-day a week or less).

Table 3 illustrates the patterns of use of motor vehicle transportation in this group. Overall, 42% reported driving on a regular basis. Most subjects also rode as passengers in private vehicles (87%) or public vehicles (61%). The analysis next categorized individuals on the basis of their primary use of motor vehicles. This was done by assigning individuals to a primary mode of transportation (driver, private vehicle passenger, public vehicle passenger) based on the highest number of miles driven or traveled within the three categories. For example, of the three categories, if the highest mileage figure reported was related to driving, the individual was categorized as primarily using motor vehicles as a driver.

When considering the primary use of transportation, we found that a large majority used private vehicles as either drivers (36%) or passengers (43%). Roughly, one person in five used public transportation as their primary means of transportation (Table 3). This category includes buses, rail transit, and para-transit. Typical drivers averaged 210 miles of vehicle use per week and most persons transferred to a vehicle seat when driving (74%). Wheelchair use as a vehicle seat was higher in persons who primarily rode as passengers in both private (56% remained in wheelchairs) and public (91% in chairs) vehicles.

Table 3 - Characteristics of Motor Vehicle Use by Persons in Wheelchairs

	Driver	Private Passenger	Public Passenger
Overall Motor Vehicle Use (%)	42.0	87.0	61.0
Primary Motor Vehicle Use (%)	36.0	43.0	21.0
Remain in Wheelchair (%)	26.0	56.0	91.0
Average Weekly Mileage	210 mi.	123 mi.	83 mi.

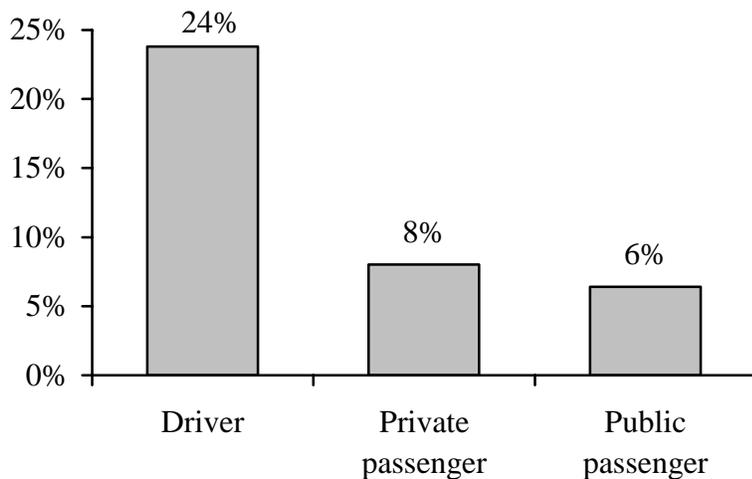
Table 4 - Percent of Respondents Reporting a Crash or Injury by Primary Type of Vehicle Use and Seating Status

	Drivers		Private Passengers		Public Passengers	
	Transfer	Wheelchair	Transfer	Wheelchair	Transfer	Wheelchair
% Reporting a Crash	20.7	34.5*	5.4	10.2*	4.3	6.5
% Reporting a Non-crash Injury	6.9	3.8	7.0	16.7*	9.1	13.6

* p-value <0.05 in the comparison by seating status

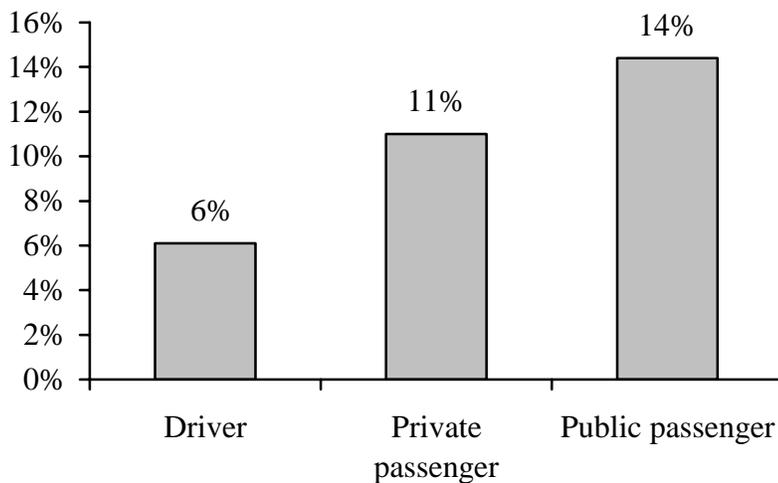
CRASH INVOLVEMENT - The frequency of involvement in a motor vehicle crash in the previous 3 years differed in this group by the pattern of primary vehicle use. Drivers reported a much higher frequency of crashes than did passengers (Figure 2). One in every 4 drivers indicated some type of crash in the previous 3 years. The type of seating used was related to crash frequency for drivers and private vehicle passengers (Table 4). Persons using wheelchairs as seats reported more crash involvement than those transferring to vehicle seats. Age group and gender were not statistically related to the reported crashes. Crash rates per mileage driven were also consistently higher among individuals who remained seated in their wheelchair compared to those who transferred to vehicle seats (drivers: 3.18 crashes per 100,000 miles driven vs. 3.07; private vehicle passengers: 4.5 vs. 1.2 crashes per 100,000 miles traveled; public vehicle passengers: 1.2 vs. 0.2 crashes per 100,000 miles traveled). These higher crash rates in wheelchair seated vehicle occupants, though, did not reach statistical significance.

Figure 2 – Percent of Respondents Reporting Involvement in Motor Vehicle Crashes



INJURIES FROM NON-CRASH SCENARIOS - Figure 3 illustrates the reported frequency of injury to wheelchair users from involvement in situations where the vehicle did not crash. These situations may include incidents where the person falls out of the chair or the wheelchair tips over due to vehicle maneuvering. Passengers, in both private and public vehicles, were more likely to report injuries from these events than drivers. Type of seating was also related to injury frequency. Its impact, though, was only observed for passengers in private vehicles (Table 4). Among private vehicle passengers, those seated in wheelchairs reported more injury events than those transferring to vehicle seats (16.7% vs. 7.0%, $p < 0.01$). No associations were observed between age group and gender and reported injuries in all three types of motor vehicle users (drivers, private vehicle passengers, and public vehicle passengers). When considering exposure, passengers seated in wheelchairs in vehicles had higher injury rates than those who transferred to vehicle seats (private vehicle passengers: 7.5 vs. 4.4 injuries per 100,000 miles traveled; public vehicle passengers: 5.2 vs. 0.6 injuries per 100,000 miles traveled, $p < 0.001$).

Figure 3 – Percent of Respondents Reporting Injury from Non-crash Incidents



DISCUSSION

The Americans with Disabilities Act has increased the social and economic opportunities available to wheelchair users. Access to and use of transportation is one aspect of this development. It is not

clear, though, what the implications of these new opportunities are with respect to transportation safety for wheelchair users.

This report examined the transportation experiences of a large group of individuals in wheelchairs. Several observations that carry safety implications were noted in the study. Overall, crash involvement was highest amongst drivers (compared to passengers), while injuries in non-crash situations were more frequent in private and public vehicle passengers (compared to drivers). The majority of wheelchair riders used private vehicles rather than public forms of transportation. Of particular importance was the finding that persons remaining in wheelchairs in vehicles appeared to be at a greater safety risk than wheelchair users who transferred to vehicle seats. Drivers and private vehicle passengers who remain in their wheelchair reported higher frequencies of crash involvement. Private vehicle passengers seated in wheelchairs also reported a greater frequency of injuries in non-crash scenarios, while public vehicle passengers seated in wheelchairs has a higher injury rate.

These findings provide some of the first evidence to reinforce the suspicions that individuals seated in wheelchairs may have a greater injury risk. The underlying theory is that occupants in vehicle seats are affected by several federal engineering standards designed to protect the occupant in a crash. Wheelchairs, on the other hand, have been designed primarily as a mobility aid. For manual chairs, this may involve features that affect weight and easy storage. For power wheelchairs, this may involve features affecting stability in everyday activities. Recent sled testing tests, though, indicate design failures when wheelchairs are subjected to the energy forces often seen in motor vehicle crashes [Bertocci, 1999].

The association suggested between seating type and crash involvement largely points to the potential for higher injury risk in wheelchair-seated vehicle occupants. This finding is intriguing, as one does not necessarily expect a causal relationship between seating type and crashes. It is likely that seating type is a marker for other factors that lead to motor vehicle crashes. These factors may include human risk-taking behaviors and decision-making, disability issues related to medical or functional impairment, or vehicular modifications, among other reasons. The design of this report, though, did not allow for an in-depth examination of the factors leading to a crash or injury event. These issues remain open for investigation in future studies.

This study is one of the first reports of the safety risks for wheelchair users in motor vehicle transport. The rationale

underlying the study was to focus on identifying the magnitude of the problem at hand. This is a common strategy used in the public health field, where prevention activities must first have a foundation that lies in identifying the importance of the issue.

The study design used in the project was specifically chosen to address this rationale and to overcome several of the limitations inherent in designs that employ existing injury surveillance systems. The study population was identified by recruiting subjects through advertisements and contact with several disability groups. This approach is appropriate for a research issue where very little information is currently known. The study population identified, though, represents a convenience sample. It is possible that the characteristics of this group may differ from the overall wheelchair using population. There are no clear data, however, to describe the characteristics that are common to persons who permanently require a wheelchair for mobility.

One could argue that a survey-based methodology is also the most appropriate approach to investigating this issue. Several problems in current surveillance systems are likely to limit their use in identifying safety risks to wheelchair users. Questionnaires allow an investigator to identify important factors affecting risk, such as the type of seating used in a vehicle, exposure data on how transportation is used, and the use of securement and restraint systems. One limitation of our survey instrument was that we did not actively query the circumstances surrounding the crashes and injuries reported. The seating details provided represent only the typical patterns of use, not the actual use at the time of a crash or injury.

Crashes and injuries were identified in this study by the self-report of the participants. While this is not the gold standard for identifying crashes, it represents a reasonable approximation for event frequency and captures events of differing severity. The limitation, though, is that respondents may not accurately recall the number of crashes or injuries incurred. They may also withhold information if they believe that it would adversely affect their future licensing status. The convenience sample methodology may also introduce a selection bias in this report, where subjects who were involved in crashes or had injuries may have preferentially chosen to participate compared to persons with no crash or injury experience.

This project supplements existing research on the engineering and biomechanics of wheelchair failure during crashes by documenting the epidemiology of the issue and by documenting likely exposures to transportation risks. This information lays the

foundation for larger studies to investigate safety risks longitudinally, to identify how these risks differ from the general population, and to develop strategies to reduce the risks faced by wheelchair users.

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