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Summary of Occupant, Wheelchair and Wheelchair Tiedown and Occupant Restraint System Configuration Data for Wheelchair-Seated Drivers and Front-Row Passengers in Private Vehicles

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16. Abstract

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Summary of Occupant, Wheelchair and Wheelchair Tiedown and Occupant Restraint System Configuration Data for Wheelchair-Seated Drivers and Front-Row Passengers in Private Vehicles

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ABSTRACT

Twenty-nine wheelchair-seated drivers and front row passengers were observed while preparing to travel in their private vehicles. Measurements were taken of the wheelchair and occupant relative to the vehicle interior and occupant restraints, using both manual and digital methods. On average, the center of the pelvic belt restraint was positioned 48.6 mm above and 27.1 mm forward of the thigh-abdominal junction of the wheelchair-seated occupants due to interference of wheelchair armrest with the lap belts, so that proper pelvic belt fit often could not be achieved. The shoulder belt was on average found to be positioned laterally 90.7 mm outboard of the center of the occupant's shoulder, so that proper shoulder belt wrapping or contact with the shoulder was not achieved in most cases. Many occupants noted having problems with the ground clearance of the docking securement hardware on the bottom of their wheelchair during everyday activities. The lowest point of the docking hardware was found to be on average 23.7 mm above the ground. The measurement information collected in this study will be used to quantify the current issues related to and to develop systems that better the safety of wheelchair-seated drivers and passengers of private vehicles.

BACKGROUND

In the United States, nearly 1.7 million people use wheelchairs for daily mobility needs [1]. For 80% of wheelchair users, public transportation is not a feasible means of transportation [1]. In a study by the University of Michigan's Health System, 87% of the 107 wheelchair users surveyed had access to a privately owned vehicle, with 55% using only this method of transportation [2]. In a recent University of Pittsburgh survey of 596 wheelchair users in 45 states, it was found that 26% of the respondents remained seated in their wheelchairs while driving personal vehicles and that these wheelchair-seated drivers had a significantly higher frequency of crash involvement than individuals who transfer to the vehicle seat [3]. Also, a study of vehicle crashes involving one or more wheelchair-seated occupants by the University of Michigan Transportation Research Institute (UMTRI) reported that, of 22 wheelchair-seated occupants involved in crashes, 7 individuals (nearly one third) died from crash-related injuries. The majority of these crashes were minor to moderate in severity and would not have resulted in fatal injuries to occupants using the vehicle seats and restraint systems [4].

The comparatively high risk of injury for wheelchair-seated occupants is partly due to the fact that they must use after-market seatbelt components that are not regulated by federal motor vehicle standards. Because of the general need for the seatbelt to be in place (i.e., passive restraint) when a wheelchair-seated driver moves forward into the driver station, the fit and placement of the belt restraints are generally such that they will not be very effective in a moderate-to-severe frontal collision, and they may even be the source of serious or fatal injuries. The effectiveness of belt restraints depends on both the lap and shoulder belt being in good contact with the occupant prior to the collision, so the belts almost immediately load the occupant, allowing him to “ride down” the vehicle deceleration as closely as possible. If belts are not initially in good contact with the body, the occupant will have a greater velocity when contact with the belt does occur, which will significantly increase the forces on body regions from the belts and further increase the likelihood of serious injuries from belt loading. Belt-restraint effectiveness also depends on the lap belt being positioned low on the pelvis near the thigh-abdominal junction and remaining in this position throughout the crash, and the shoulder belt being positioned over the middle of the shoulder and across the center of the sternum. If the lap belt rides up on the abdomen, the occupant will slide under the belt, increasing the likelihood of injuries to the abdomen and lumbar spine. If the shoulder belt comes off the shoulder, large excursions of the head and chest will occur, thereby increasing the likelihood of serious head, neck, and thoracic injuries.

In addition to issues related to effective occupant restraint, wheelchair-seated drivers face the potential hazard imposed by contact with specially-installed grip enhancing hand controls and assistive steering systems. Specially designed hand controls, reduced-effort steering, electronic gas and brake controls and touch pads to activate secondary controls such as power windows and climate controls are also available for wheelchair-seated drivers with limited upper-extremity function. In some cases, it is necessary to alter or remove federally-required safety equipment to enable individuals seated in wheelchairs to drive [5]. When adapting vehicles for wheelchair-seated drivers, OEM safety belts are often altered or replaced by alternative seat belt systems [5]. No information is available in the literature on how these systems protect wheelchair seated drivers. Additionally, it is unclear how the design and installation of vehicle control systems and removing/disconnecting airbags can affect wheelchair occupant injury risk in motor vehicles.

STUDY OBJECTIVE

The objective of the study was to investigate and document issues of transportation safety and usability by adults who remain seated in their wheelchairs when traveling in their personal vehicles. As a first step toward this goal, measurements were taken with respect to the position of the wheelchair-seated occupants relative to the interior vehicle space, including steering controls and assistive grip devices, as well as relative to the occupant restraints, including three-point lap and shoulder belts. Additional measurements were to taken to document the position of the wheelchair securement system components, such as the docking securement device and the wheelchair-docking adaptor, relative to the vehicle interior and to the wheelchair, respectively. This study will provide quantitative information regarding the in-vehicle environment of the wheelchair-seated occupant in order to address safety issues and thereby improve the designs of wheelchairs and restraint systems.

METHOD

Data were collected for 29 individuals who drive or ride as a front row passenger in a private vehicles while seated in their wheelchairs. Participants were recruited from the western Pennsylvania and southeastern Michigan areas. Subjects were observed while entering their private vehicle, securing their wheelchair in the wheelchair passenger station and donning the occupant restraint belts (when applicable). Once in position for travel, photographs of the seat belt configuration and the position of wheelchair and occupant relative to the vehicle interior were taken. Measurements were taken of the wheelchair and occupant relative to the vehicle interior and occupant restraints, using both manual and digital methods. Digital measurements were achieved using a FARO arm digitizing device, shown in Figure 1 below, which collects data on the three-dimensional locations of points or targets contacted by the tip of a probe at the end of the articulating arm.

Figure 1. Measurements using a FARO arm.

Key dimensions such as the side-view lap-belt angle, belt-to-body contact distances, locations of the lap belt relative to the tops of the thighs, and location of the shoulder belt relative to the center of the shoulder were recorded. In addition, distances between the occupant and important vehicle interior components, such as the center of the steering wheel, hand controls, the B-pillar, and the knee bolster were measured and recorded. Measurement data were compiled, edited and analyzed separately for drivers and passengers. Mean values and standard deviations of the measurement data were computed.

RESULTS AND DISCUSSION

During this study, 21 wheelchair-seated drivers and 8 front-row passengers were recruited for participation. Four of these subjects (all drivers) used manual wheelchairs with power assist features, and the remaining 25 subjects were using powered wheelchairs. The average age of the subjects was 50 years. On average, subjects had used private vehicles while seated in their wheelchairs for 20.4 years. The subjects indicated that they operate or ride in their vehicle on average about 4.8 days per week and about 1.4 hours per day.

The minimum, maximum, mean and standard deviations for each of the measurements collected during this study are listed in Tables 3 through 6 for drivers and passengers separately in the attached appendix. The combined wheelchair-seated driver and passenger data are listed in Tables 1 and 2. Illustrations of the measurements are also provided as Figures _ through _ in the appendix.

Twenty-three subjects secured their wheelchair in the vehicle using an automated docking-type securement system (EZ-lock or Q'Straint QLK), while 4 subjects (all passengers) used a four-point strap-type tiedown with the assistance of an attendant or caregiver. Two subjects drove or rode in their vehicle with their wheelchairs completely unsecured. During the interview portion of the study, several of the subjects using a docking-type securement device mentioned that they had problems with the low height of the docking hardware on the wheelchair (i.e., the drop-down bolt that engages with the docking device) causing the hardware to catch on entryway thresholds and rug edges during everyday use. The average height of the docking hardware above the ground, as shown in Figure __, for these 23 subjects was 23.7 mm (± 9.7 mm).

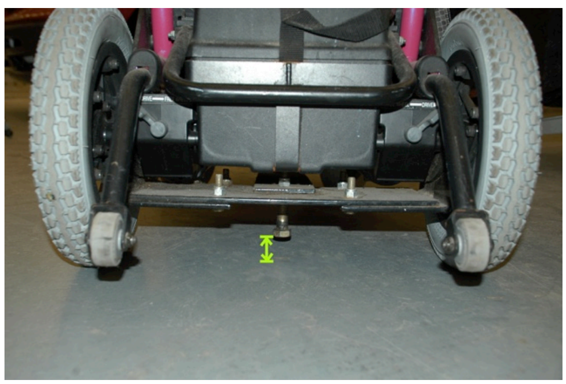

Figure __. Docking Hardware Height Above the Ground.

Nineteen subjects used a non-modified original equipment manufacturer (OEM) lap/shoulder belt in their vehicle, with an added after-market stalk or length of webbing attached to the buckle receptacle on the inboard side. Two vehicles were equipped with complete after market seat belt systems and one subject simply wrapped the OEM lap/shoulder belt around the inboard seatback cane of their wheelchair instead of buckling their seatbelt for restraint. One subject's wheelchair was equipped with a crashworthy wheelchair-anchored lap belt that was used in conjunction with a passive (requiring no donning action from the occupant) aftermarket shoulder belt. Another subject relied on a passive aftermarket shoulder belt only and 5 subjects did not use any occupant restraint while driving or riding in their vehicle.

Investigators observed poor seatbelt fit in many cases; pelvic restraints were routed over the top of or in front of the wheelchair armrests, so that the pelvic belt did not make contact with the occupant or it was positioned above the pelvis and on the abdomen. The average height of the center of the pelvic belt above the occupant's thigh-abdominal junction, as illustrated in Figure __a below, was 48.6 mm (± 61.6 mm) and on average the pelvic belt was 27.1 mm (± 62.3 mm) forward of the thigh abdominal junction, as show in Figure __b below, due in many cases to interference of the wheelchair armrest with proper positioning of the pelvic belt.

(a) *(b)*

Figure __. Occupant Belt Position Relative to the Thigh-abdominal Junction.

The wheelchairs were often secured farther rearward in the vehicle when compared to the position of the original vehicle seat due to the addition of footrests on the wheelchair. This caused the fore-aft position of the wheelchair-seated occupant's hip to be located closer to the position of the lower anchorages of the lap belt on the floor, often resulting in steep lap belt angles and making the option of routing the lap belt between the armrest and seatback of the wheelchair for better belt fit on the occupant's pelvis nearly impossible. The average side-view angle of the inboard lap belt with respect to horizontal was 59.6° (± 18°) and the average side-view angle of the lap belt on the outboard side of the vehicle was 54.4° (± 20°).

Shoulder belts, when used, were often routed off of the edge of the shoulder or were very slack. Several subjects mentioned that the shoulder belt did not provide enough upper torso support so that they often felt very unstable while maneuvering the vehicle around turns, while others felt that a shoulder belt with a retractor was often too tight so that it pushed their torso laterally when they were in position to drive or ride as a passenger in the vehicle. The average lateral distance from the center of the shoulder belt (measured at the height of the top of the shoulder) to the center of the subject's shoulder (measured at the acromion) was 90.7 mm (± 77.7 mm) as illustrated in Figure __ below.

A poor shoulder belt position was often the result of a poorly positioned upper anchorage point (D-ring) on the vehicle B-Pillar and the result of the wheelchair's excessive width forcing the wheelchair-occupant's seat position to be shifted inboard of the original vehicle seat position. Also, the D-ring position on the vehicle's B-Pillar was sometimes in the same fore-aft position as or in front of the occupant's shoulder because the wheelchairs were frequently positioned farther rearward in the vehicle when compared to the original vehicle seat position. On average, the subject's shoulder was 163.9 mm (± 222.5 mm) forward of the D-ring position on the vehicle B-Pillar. This resulted in poor shoulder belt contact or wrapping over the upper portion of the wheelchair-seated subject's shoulder in many cases.

Figure __. Shoulder Belt Position Relative to the Center of the Shoulder.

Thirteen of the 21 wheelchair-seated drivers used various types of steering-grip enhancers that were installed on the OEM steering wheel, including triple-pins (tri-pin), V-grips, and spinner knobs. An example steering-grip enhancer is shown below in Figure __ a. Eight other drivers used a reduced-diameter wheel or a joystick (Figure __b) instead of the OEM steering wheel. These latter two devices could be adjusted to the left, to the right, or in front of the driver, depending on the driver's preference and functional reach.

Figure __: Examples of Grip Enhancer and Steering Controls.

While the horizontal distances between the drivers' chins and the center of the standard steering wheel are reasonable and similar to those for drivers seated in vehicle seats (6), the distances to the add-on steering controls and grip-enhancers, and the distances between the drivers' abdomens and the lower rim of the steering wheel, as shown in Figure__, are considerably smaller. On average, the driver's chin was positioned 210.5 mm (± 99.1 mm) rearward from the steering control device and the driver's abdomen was 123.9 mm (± 80.3 mm) from the lower rim of the steering wheel.

Figure __: Driver's Chin and Abdomen Position Relative to the Steering Grip Enhancer and the Lower Rim of the Steering Wheel.

CONCLUSIONS

Safety issues for wheelchair-seated drivers and passengers in private vehicles were assessed. Interference of wheelchair frames with occupant restraints, the vehicle interior and control systems were frequently observed. An inability to reach and operate seat belts and the unavailability of head restraints was often reported by subjects. As a result, seat belts are often misused, routed over armrests, or around clothing guards, or are not used at all. Because the effectiveness of belt restraints in protecting drivers in frontal crashes depends on proper belt positioning on the occupant prior to the collision, which is largely dependent on the ease of achieving proper belt fit, it can be expected that the use of open-front armrests on the wheelchair will markedly increase occupant crash protection for wheelchair-seated drivers. It can also be expected that open-front wheelchair armrests will facilitate proper restraint positioning by vehicle operators and caregivers who assist wheelchair-seated passengers when traveling in private, para-transit, and public transportation vehicles. The results of this study provide information for wheelchair manufacturers that seek to improve wheelchair and armrest designs to better accommodate proper seatbelt use and positioning, and therefore the overall transportation safety for wheelchair-seated drivers. The results will also be useful for wheelchair prescribers when recommending wheelchairs and armrest configurations for people who expect to drive a personal vehicle while seated in their wheelchair.

Steering control configuration and positioning relative to wheelchair-seated drivers were measured in 15 modified vehicles. The results from this study provide researchers with the geometric information of steering-control positioning with respect to wheelchair-seated drivers. The results also show that proper seatbelt positioning and use is often compromised for wheelchair-seated driver by interference from wheelchair armrests or other wheelchair components. Common types of steering configurations used by drivers seated in wheelchairs include tri-pins, mini-wheels, spinner knobs, and joysticks. Close proximity of drivers to some steering controls such as tri-pins, joy-sticks, reduced-diameter wheels, and spinner knobs, in combination with a lack of proper seatbelt fit and/or use can be expected to adversely affect wheelchair occupant injury risk during frontal motor vehicle impacts.

Although wheelchair-seated drivers and passengers were often using improperly and poorly positioned and incomplete belt restraints and reported being unable to independently exit their vehicle in an emergency situation, most respondents reported feeling safe when driving or riding in their vehicles. Nevertheless, the observations made in this study, coupled with knowledge of what is required for effective occupant restraint and crash protection, have made it clear that improvements in seatbelt systems for wheelchair seated riders in private vehicles are badly needed. These improvements require not only innovative designs in passive (automatic) seatbelt systems but changes in the design of wheelchairs to reduce interference with proper seatbelt fit.

Limitations of this study include the relatively small number of subjects tested to date and the fact that most of the special equipment required by the wheelchair drivers was installed by a few van modifiers in the Pittsburgh and southeast Michigan areas. The results of this study will be used to guide the design of improved driver controls and seatbelt systems for wheelchair-seated drivers. They will also be used to further investigate the effects of control positioning on wheelchair driver injury risk in frontal collisions.

Table 1: Distances from steering device to the driver's chin and abdomen.

Figure 3: Distances measured between driver and control device for 15 subjects.

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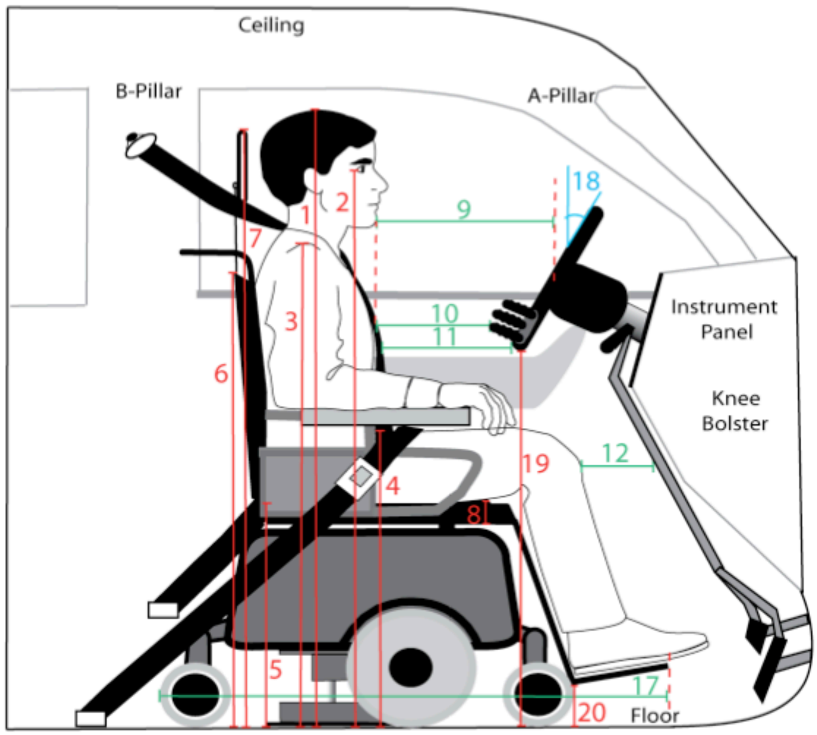
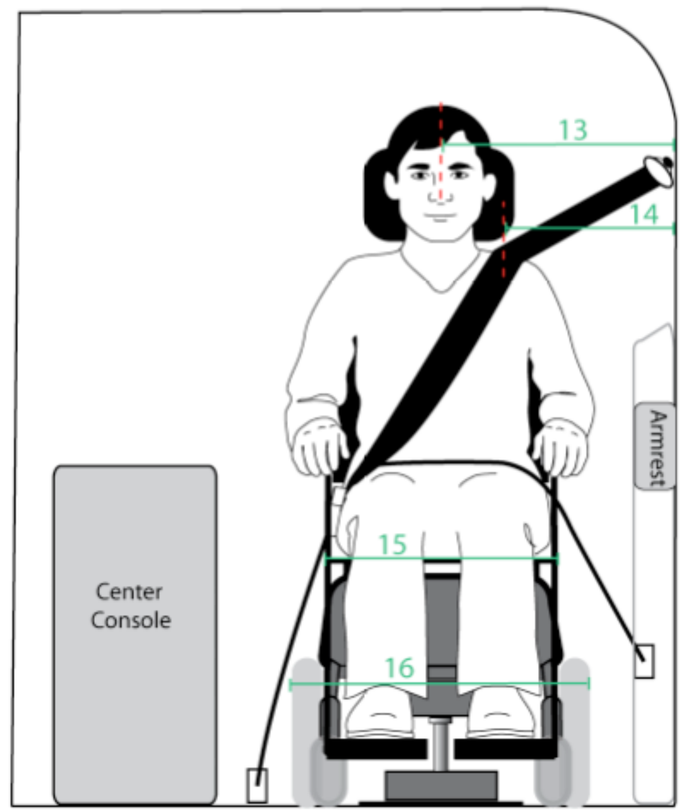
APPENDIX

Table 1. Measurements of the Wheelchair and Occupant Relative to the Vehicle Interior Space for Combined Group of Drivers and Passengers (n = 29).

Measurement		Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
1	Height of top of head relative to vehicle floor	1219.2	1326.2	72.5	1559.9
2	Height of corner of eye relative to vehicle floor	1092.2	1216.8	72.3	1462.8
3	Height of top of shoulder relative to vehicle floor	967.7	1080.5	67.7	1292.3
4	Height of thigh-abdominal junction relative to vehicle floor	584.2	709.1	73.7	988.3
5	Height of seat bight relative to vehicle floor	406.4	551.8	81.2	812.5
6	Height of top of wheelchair backrest relative to vehicle floor	849.9	1004.2	106.0	1373.8
7	Height of top of wheelchair headrest relative to vehicle floor	1167.0	1274.7	66.1	1426.3
8	Seat cushion thickness	30.4	81.6	23.1	127.0
12	Fore-aft distance from knee bolster to knee	0.0	134.4	123.0	449.4
13	Lateral distance from vehicle side-wall/B-pillar to centerline of subject	190.5	318.9	63.8	473.4
14	Lateral distance from vehicle side-wall/B-pillar to center of outboard shoulder	61.5	176.6	66.4	320.2
15	Wheelchair width at seat bite	262.3	438.8	69.8	584.2
16	Wheelchair width at widest point (drive wheel)	515.1	636.5	40.0	736.1
17	Wheelchair length (footprint)	750.5	1112.0	111.9	1268.9
20	Height of footrest bottom relative to vehicle floor	52.1	127.8	41.9	194.0



(a)

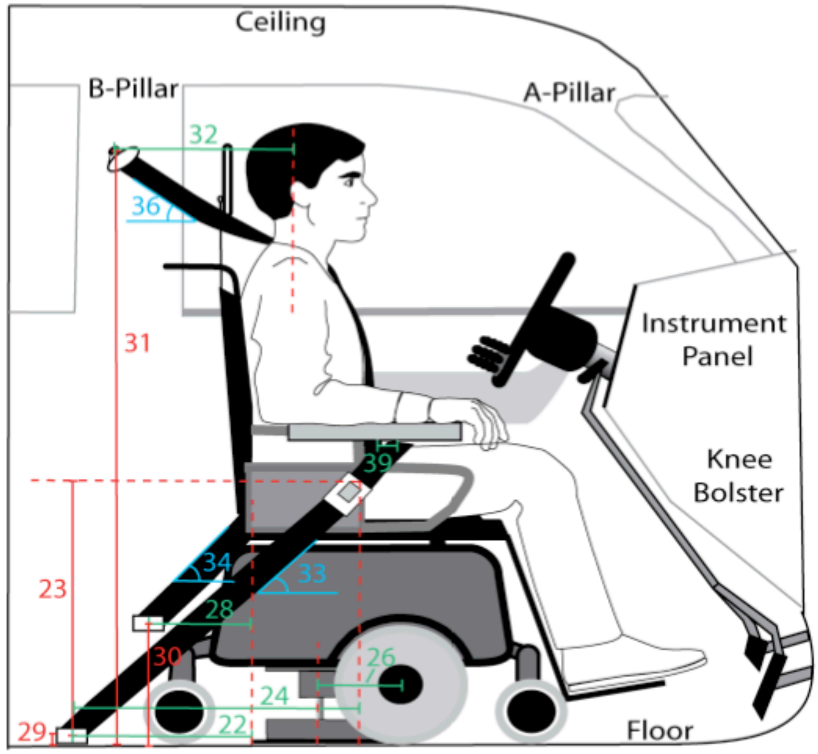


(b)

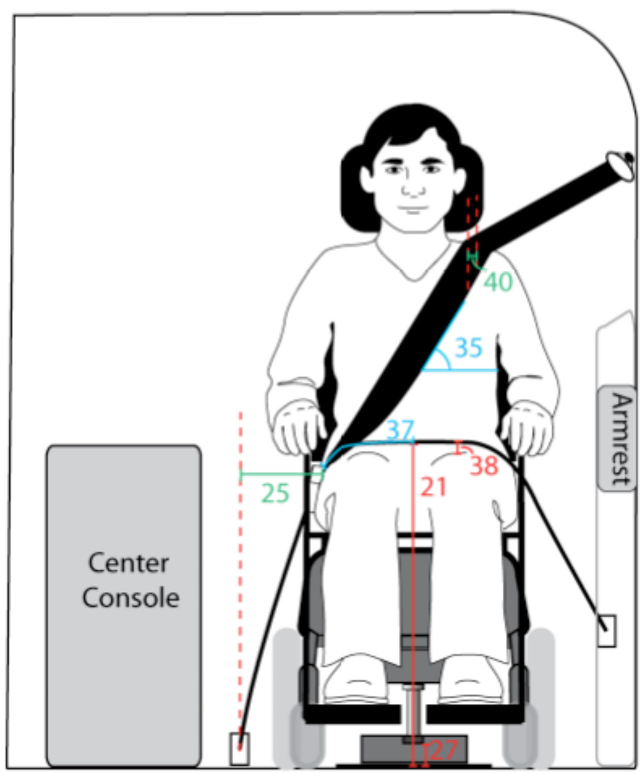
Figure ___. Illustration of Measurements of the Wheelchair and Occupant Relative to the Vehicle Interior Space.

Table 2. Measurements of the Wheelchair Tiedown and Occupant Restraint System Relative to the Occupant and Vehicle Interior Space for Combined Group of Drivers and Passengers (n = 29).

	Measurement	Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
21	Height of center of lap belt at subject midline relative to vehicle floor	633.1	729.3	71.2	901.0
22	Fore/aft distance of inboard lap-belt anchor point relative to seat bite	-167.0	35.4	156.9	551.9
23	Height of inboard lap-belt latch plate relative to stock anchor point	130.2	525.2	184.8	846.0
24	Fore/aft distance of inboard lap-belt latch plate relative to stock anchor point	2.4	208.5	134.4	473.9
25	Lateral distance from inboard lap-belt latch plate to stock anchor point	-63.5	144.8	116.6	520.0
26	Fore/aft distance of (EZ-lock) securement bolt to center axle of wheelchair driving wheel	-128.9	25.5	93.0	228.6
27	Height of EZ-Lock securement bolt relative to vehicle floor	12.5	23.7	9.7	42.8
28	Fore/aft distance of outboard lap-belt anchor point relative to seat bite	-1006.9	-17.5	239.7	319.2
29	Height of inboard lap-belt anchor point relative to vehicle floor	0.0	154.9	184.3	546.1
30	Height of outboard lap-belt anchor point relative to vehicle floor	0.0	282.2	161.8	692.9
31	Height of upper shoulder-belt anchor point relative to vehicle floor	1005.8	1161.1	58.8	1269.7
32	Fore/aft distance from the upper shoulder-belt anchor point to the center of the subject's shoulder	-373.7	163.9	222.5	1076.1
33	Side-view angle of inboard lap belt with respect to horizontal	24.2	61.4	17.0	86.0
34	Side-view angle of outboard lap belt with respect to horizontal	5.3	55.0	19.6	80.0
35	Front-view angle of shoulder belt with respect to horizontal	16.0	38.0	11.8	63.0
36	Side-view angle of shoulder belt between shoulder and upper anchor point with respect to horizontal	7.6	28.8	14.9	68.0
37	Distance along the lap belt from the occupant midline to the junction of the lap/shoulder belt	114.3	299.7	140.9	584.2
38	Height of center of lap belt relative to thigh-abdominal junction	-1.4	48.6	61.6	235.6
39	Smallest fore/aft distance from thigh-abdomen junction to center of lap belt at the midline	0.0	27.1	62.3	201.6
40	Fore/aft distance from knee bolster to center of patella	0.0	134.4	123.0	449.4
41	Lateral distance from center of outboard shoulder to center of shoulder belt at top of shoulder	-50.8	90.7	77.7	220.8



(a)



(b)

Figure ___. Illustration of Measurements of the Wheelchair Tiedown and Occupant Restraint System Relative to the Occupant and Vehicle Interior Space.

Table 3. Measurements of the Wheelchair and Occupant Relative to the Vehicle Interior Space for Drivers (n = 21).

Measurement		Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
1	Height of top of head relative to vehicle floor	1223.6	1327.8	75.0	1559.9
2	Height of corner of eye relative to vehicle floor	1130.3	1219.4	72.7	1462.8
3	Height of top of shoulder relative to vehicle floor	967.7	1077.3	71.7	1292.3
4	Height of thigh-abdominal junction relative to vehicle floor	584.2	713.1	78.2	988.3
5	Height of seat bight relative to vehicle floor	406.4	558.1	81.3	812.5
6	Height of top of wheelchair backrest relative to vehicle floor	849.9	987.5	114.3	1373.8
7	Height of top of wheelchair headrest relative to vehicle floor	1203.1	1257.7	34.4	1282.7
8	Seat cushion thickness	30.4	76.4	23.6	101.6
9	Fore-aft distance from center of steering wheel to chin	115.6	313.6	83.2	508.0
10	Fore-aft distance from other steering control device to chin	22.3	210.5	99.1	372.6
11	Fore-aft distance from lower steering-wheel rim to abdomen	2.5	123.9	80.3	304.8
12	Fore-aft distance from knee bolster to knee	0.0	75.9	61.3	158.7
13	Lateral distance from vehicle side-wall/B-pillar to centerline of subject	190.5	307.2	61.6	443.9
14	Lateral distance from vehicle side-wall/B-pillar to center of outboard shoulder	76.2	165.2	59.2	320.2
15	Wheelchair width at seat bite	262.3	433.6	78.3	584.2
16	Wheelchair width at widest point (drivewheel)	515.1	637.4	46.0	736.1
17	Wheelchair length (footprint)	750.5	1091.3	117.9	1268.9
18	Steering wheel angle with respect to vertical	18.6	31.3	6.2	40.4
19	Height of lower steering wheel rim relative to vehicle floor	620.2	736.4	46.1	804.7
20	Height of footrest bottom relative to vehicle floor	52.1	116.7	41.8	168.6

Table 4. Measurements of the Wheelchair Tiedown and Occupant Restraint System Relative to the Occupant and Vehicle Interior Space for Drivers (n = 21).

	Measurement	Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
21	Height of center of lap belt at subject midline relative to vehicle floor	633.1	717.3	63.7	850.9
22	Fore/aft distance of inboard lap-belt anchor point relative to seat bite	-167.0	7.3	111.4	279.4
23	Height of inboard lap-belt latch plate relative to stock anchor point	130.2	510.1	175.7	777.5
24	Fore/aft distance of inboard lap-belt latch plate relative to stock anchor point	2.4	221.6	147.0	473.9
25	Lateral distance from inboard lap-belt latch plate to stock anchor point	-63.5	129.6	94.3	273.5
26	Fore/aft distance of (EZ-lock) securement bolt to center axle of wheelchair driving wheel	-128.9	34.6	94.7	228.6
27	Height of EZ-Lock securement bolt relative to vehicle floor	12.5	23.8	10.7	42.8
28	Fore/aft distance of outboard lap-belt anchor point relative to seat bite	-284.1	-4.3	113.9	177.8
29	Height of inboard lap-belt anchor point relative to vehicle floor	0.0	171.8	189.0	546.1
30	Height of outboard lap-belt anchor point relative to vehicle floor	40.5	287.9	138.0	657.6
31	Height of upper shoulder-belt anchor point relative to vehicle floor	1005.8	1152.7	60.0	1269.7
32	Fore/aft distance from the upper shoulder-belt anchor point to the center of the subject's shoulder	0.0	144.4	68.7	278.3
33	Side-view angle of inboard lap belt with respect to horizontal	24.2	59.6	17.8	86.0
34	Side-view angle of outboard lap belt with respect to horizontal	5.3	54.4	20.0	80.0
35	Front-view angle of shoulder belt with respect to horizontal	16.0	39.1	12.2	63.0
36	Side-view angle of shoulder belt between shoulder and upper anchor point with respect to horizontal	7.9	30.5	15.8	68.0
37	Distance along the lap belt from the occupant midline to the junction of the lap/shoulder belt if used as a three-point belt	114.3	308.4	169.9	584.2
38	Height of center of lap belt relative to thigh-abdominal junction	-1.4	41.8	47.5	152.4
39	Smallest fore/aft distance from thigh-abdomen junction to center of lap belt at the midline (value is 0 if belt in contact with subject)	0.0	15.9	47.2	177.8
40	Fore/aft distance from knee bolster to center of patella	0.0	75.9	61.3	158.7
41	Lateral distance from center of outboard shoulder to center of shoulder belt at top of shoulder	-50.8	95.0	85.9	220.8

Table 5. Measurements of the Wheelchair and Occupant Relative to the Vehicle Interior Space for Passengers (n = 8).

Measurement		Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
1	Height of top of head relative to vehicle floor	1219.2	1321.9	70.3	1422.6
2	Height of corner of eye relative to vehicle floor	1092.2	1210.0	76.0	1307.5
3	Height of top of shoulder relative to vehicle floor	985.2	1089.1	59.2	1182.7
4	Height of thigh-abdominal junction relative to vehicle floor	609.6	698.6	63.7	821.9
5	Height of seat bight relative to vehicle floor	431.8	535.3	84.0	662.0
6	Height of top of wheelchair backrest relative to vehicle floor	921.9	1048.1	67.7	1104.9
7	Height of top of wheelchair headrest relative to vehicle floor	1167.0	1286.9	82.5	1426.3
8	Seat cushion thickness	76.2	95.0	16.2	127.0
9	Fore-aft distance from center of instrument panel to chin	406.4	663.4	205.8	1042.2
11	Fore-aft distance from center of instrument panel to abdomen	304.8	506.8	188.6	845.9
12	Fore-aft distance from knee bolster to knee	132.5	263.1	131.4	449.4
13	Lateral distance from vehicle side-wall/B-pillar to centerline of subject	254.0	349.6	62.6	473.4
14	Lateral distance from vehicle side-wall/B-pillar to center of outboard shoulder	61.5	206.6	78.9	288.6
15	Wheelchair width at seat bite	384.7	451.3	45.8	507.2
16	Wheelchair width at widest point (drivewheel)	607.2	634.0	18.5	664.9
17	Wheelchair length (footprint)	1016.0	1166.5	75.4	1240.9
20	Height of footrest bottom relative to vehicle floor	102.7	147.7	37.7	194.0

Table 6. Measurements of the Wheelchair Tiedown and Occupant Restraint System Relative to the Occupant and Vehicle Interior Space for Passengers (n = 8).

Measurement		Minimum (mm/deg)	Average (mm/deg)	Standard Deviation (mm/deg)	Maximum (mm/deg)
21	Height of center of lap belt at subject midline relative to vehicle floor	660.4	763.2	86.4	901.0
22	Fore/aft distance of inboard lap-belt anchor point relative to seat bite	29.4	204.3	301.0	551.9
23	Height of inboard lap-belt latch plate relative to stock anchor point	199.3	567.9	220.3	846.0
24	Fore/aft distance of inboard lap-belt latch plate relative to stock anchor point	4.9	171.2	89.7	228.6
25	Lateral distance from inboard lap-belt latch plate to stock anchor point	80.0	188.0	168.5	520.0
26	Fore/aft distance of (EZ-lock) securement bolt to center axle of wheelchair driving wheel	-127.0	-20.1	78.5	61.2
27	Height of EZ-Lock securement bolt relative to vehicle floor	20.4	23.1	3.8	25.8
28	Fore/aft distance of outboard lap-belt anchor point relative to seat bite	-1006.9	-59.4	475.6	319.2
29	Height of inboard lap-belt anchor point relative to vehicle floor	16.4	101.4	173.0	453.2
30	Height of outboard lap-belt anchor point relative to vehicle floor	0.0	265.0	235.1	692.9
31	Height of upper shoulder-belt anchor point relative to vehicle floor	1108.0	1189.1	48.7	1227.8
32	Fore/aft distance from the upper shoulder-belt anchor point to the center of the subject's shoulder	-373.7	228.6	472.3	1076.1
33	Side-view angle of inboard lap belt with respect to horizontal	45.0	66.3	14.9	81.1
34	Side-view angle of outboard lap belt with respect to horizontal	17.0	56.9	20.2	74.2
35	Front-view angle of shoulder belt with respect to horizontal	20.0	34.5	10.4	45.0
36	Side-view angle of shoulder belt between shoulder and upper anchor point with respect to horizontal	7.6	22.3	9.1	30.0
37	Distance along the lap belt from the occupant midline to the junction of the lap/shoulder belt if used as a three-point belt	254.0	279.4	44.0	330.2
38	Height of center of lap belt relative to thigh-abdominal junction	0.0	66.7	92.8	235.6
39	Smallest fore/aft distance from thigh-abdomen junction to center of lap belt at the midline (value is 0 if belt in contact with subject)	0.0	56.9	90.3	201.6
40	Fore/aft distance from knee bolster to center of patella	132.5	263.1	131.4	449.4
41	Lateral distance from center of outboard shoulder to center of shoulder belt at top of shoulder	21.0	75.2	38.2	112.6