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Investigation of Vehicle Ingress and Egress: Correlating Vehicle Geometry to Subject Ratings

FINAL REPORT

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16. Abstract: This study was conducted to investigate the effects of vehicle doorway geometry, including rocker-panel height to heel surface, rocker-panel width, seat-to-ground distance, and door-pivot mechanisms on driver perception of ease or difficulty of ingress and egress. In addition, two methodologies were investigated for use in ingress/egress studies. Five subpopulations of subjects, whose age and physical characteristics were considered to have a possible influence on perception of the ease of ingress/egress, were tested using both Ratings and Paired Comparisons procedures for assessing ease of ingress and egress. Rocker-panel height and width, and seat-to-ground distance were varied over ranges spanning current production vehicle dimensions. Testing was conducted using an adjustable laboratory buck and primarily for constrained door-opening conditions, similar to door-openings allowed in typical parking lots. Door hinge characteristics were varied to explore the possible advantages of a four-bar hinge mechanism under these constrained conditions. The test facility was instrumented to measure forces exerted by subjects on the ground, seat, and steering wheel during both ingress and egress trials.

Analysis of the test data show that: (1) Ratings and Paired Comparisons methods are both viable for use in ingress/egress testing; (2) egress is perceived to be more difficult than ingress across conditions; (3) rocker width and seat-to-ground distance have an important influence on perception of the ease of ingress/egress; (4) door-hinge influenced subject ratings of ingress and egress, but the four-bar hinge conditions were generally rated as more difficult than the production-hinge condition; (5) subject groups differ in their overall rating of ease of ingress and egress, with elderly subjects reporting greater difficulty across all conditions; (6) the effect of rocker width and seat-to-ground distance on rating difficulty of ingress and egress varies for different subject groups; (7) subject ratings were repeatable within and across sessions; (8) seat-to-ground distance has an important influence on subject ratings; (9) subjects rarely judged conditions to be unacceptably difficult; and (10) parameters of the force-time histories were significantly affected by vehicle variables, but they were not closely related to difficulty ratings.

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1.0 BACKGROUND

Entering and exiting a vehicle are tasks associated with driving a vehicle, but few studies have focused on the elements of vehicle design that influence the difficulty of ingress and egress, and no studies have successfully correlated vehicle design features and dimensions with ease or difficulty of ingress/egress. Of those that have been done, most have focused exclusively on elderly or disabled drivers (e.g., Koester and Hamilton 1994, James 1985). While people in these populations are likely to be particularly sensitive to difficulties in ingress/egress imposed by vehicle design, it is important to understand how vehicle doorway design and position of the opened door affects ingress/egress difficulty for the general adult population.

A study by Loczi (1993) used young, able-bodied subjects to measure a set of kinetic and kinematic posture variables under a variety of vehicle doorway conditions. The doorway factors tested included seat-to-ground distance, door-to-ground distance, and fore/aft seat position (relative to the steering wheel) but did not include a door. It was found that seat-to-ground and door-to-ground distances significantly affect knee and hip flexion angles. Based on the hypothesis that smaller knee and hip flexion angles are associated with less effort, Loczi reported optimal values of these vehicle doorway variables for reducing effort in ingress/egress. These results provide a valuable insight into understanding a complex task, but because subjective measures of ease of ingress/egress under different vehicle conditions were not obtained, the results cannot be directly linked to drivers' perceptions.

Another study that quantified the relationship between vehicle doorway parameters and subjective measures of ingress/egress difficulty was reported by James (1985). The subjects were either elderly or disabled, but the results provide useful data that may be relevant to other populations. One phase of this study was conducted in a laboratory buck, in which several parameters of the doorway were adjustable, including seat-to-ground distance, seat-to-rocker-panel lateral distance, and rocker-to-vehicle-floor vertical distance but there were no doors. These parameters were not varied factorially, but rather, subjects adjusted them to be within acceptable boundaries one at a time. Percent acceptance as a function of vehicle factor level was calculated from these data.

2.0 STUDY OVERVIEW

In recent years, the trend in automobile design has been to widen the front tread (i.e., the lateral distance between the centers of the front tires) of passenger vehicles. This is done to accommodate emission requirements (i.e., catalytic converters), to enhance structural design for crashworthiness concerns (i.e., increased width of longitudinal rails), to increase lateral stability (especially for utility vehicles), and for appearance considerations. The need to reduce paint damage on the car body has resulted in a consequent increase in rocker-panel distance from the center of the driver's seat. The effect of this dimensional change and the associated increased thickness of lower doors on driver ingress/egress is not known, but there is concern that it may result in a significant increase in difficulty and/or unacceptability of occupant ingress and egress, particularly for some segments of the population.

This concern, as well as a need to conduct a baseline study of ingress/egress (I/E) methodology for using both subjective and objective measures, led to the present study. The study uses five subpopulations of subjects* whose characteristics were considered to

[1]The rights, welfare, and informed consent of the volunteer subjects who participated in this study were observed under guidelines established by the U.S. Department of Health, Education, and Welfare (now

have a possible influence on perception of the ease of ingress/egress. Two doorway vehicle parameters, rocker-panel height and width, as well as seat-to-ground distance, were varied over ranges approximately spanning current production vehicle dimensions in a factorial combination, and both subjective and objective measurements of each entry/exit task were obtained. Testing was conducted using an adjustable laboratory buck and primarily for constrained door-opening conditions, similar to door-opening conditions allowed in typical parking-lot situations. Door hinge characteristics were also varied to explore the possible advantages of a four-bar mechanism hinge under these constrained conditions. In addition, two different methodological procedures for collecting subjective perceptions of the ease of the ingress/egress task under different vehicle conditions were used and compared.

3.0 STUDY OBJECTIVES

Within the constraints and conditions noted above, the specific objectives of this study were to:

1. compare results from two different data-collection techniques (Paired Comparisons and Ratings) to determine which can be used most effectively for Ingress/Egress (I/E) studies,
2. investigate the consistency of subjects' ability to differentiate between vehicle configurations,
3. investigate the effects of door-opening factors, vehicle seat-height-to-ground distance, and other doorway dimensions on driver I/E preference,
4. investigate whether objective measures of force exerted on the seat, ground, and steering wheel are related to subjects' perceptions of the I/E task,
5. investigate the influence of subject age and anthropometry on ease of I/E, and
6. investigate the interactions between subject perceptions of I/E tasks and subject characteristics, vehicle doorway dimensions, and seat-to-ground distance.

4.0 METHODS

4.1 Ingress/Egress Parameters and Test Facility

The study was conducted in a laboratory buck designed to simulate interior and exterior features of a Taurus-like passenger vehicle, with a nominal seat height (H30) distance of 270 mm. The buck allows for quick and easy adjustment of the three vehicle parameters illustrated in Figure 1, including:

- Hz = SgRP-to-ground distance,
- W = seat C/L-to-rocker lateral distance, and
- D = top-of-rocker-to-vehicle floor (AHP) vertical distance.

Health and Human Services) on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, Medical School, The University of Michigan.

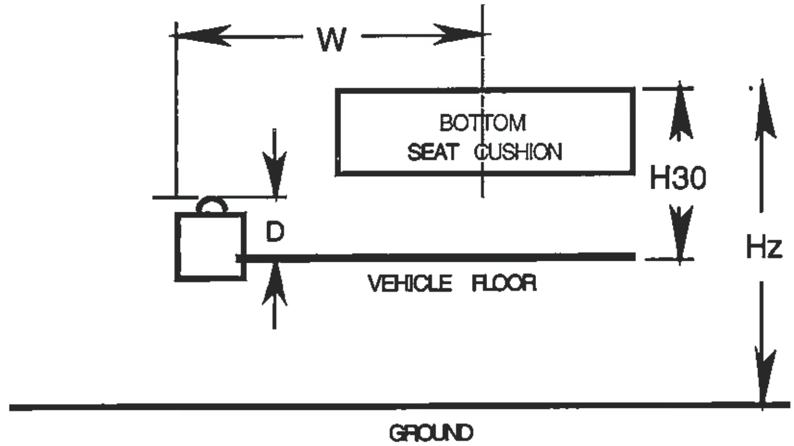

Figure 1. Rear-view schematic drawing of driver area illustrating vehicle parameters used in testing.

Figures 2a and 2b show the adjustable laboratory test buck, which is illustrated schematically in Figure 3. Additional photographs of the test facility are shown in Appendix H. The clip of a 1994 Taurus vehicle from the firewall to the C-pillars (behind rear seat) was mounted on top of a hydraulic lift platform that provided for quick adjustment of seat-to-ground distance over the range of interest. The interior package includes a vehicle seat, steering wheel and column, instrument panel, brake and accelerator pedal assemblies, and floor and toe board. The driver doorway includes the A-pillar, B-pillar, roof rail, door, and rocker panel of an actual vehicle. The production door rocker or sill was cut out and attached to a dual-axis, linear-motion device located under the vehicle floor surface, which provided for independent adjustment of the lateral and vertical distance of the rocker relative to the seat and driver heel surface. Adjustment to different rocker positions for testing was accomplished by use of a power-activated screw-motor actuator, controlled by a set of toggle switches.

Figure 2a. Photograph of the laboratory ingress/egress buck.

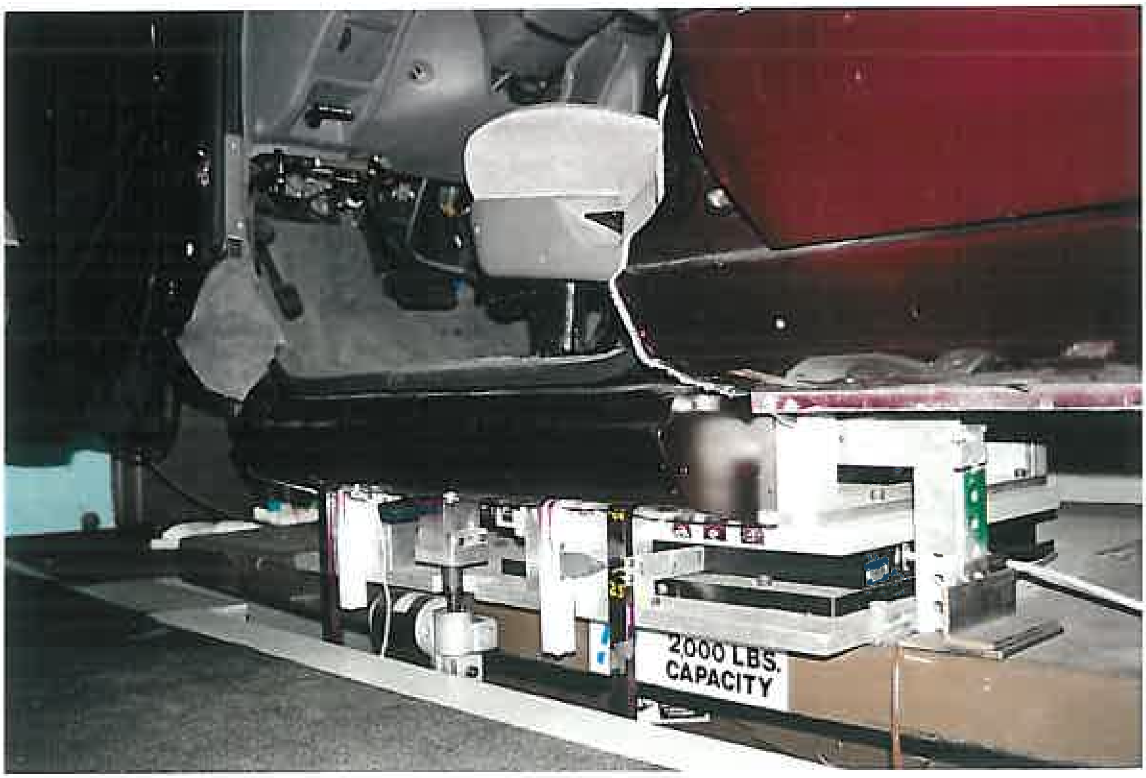

Figure 2b. Closeup showing the adjustable rocker panel of the laboratory ingress/egress buck.

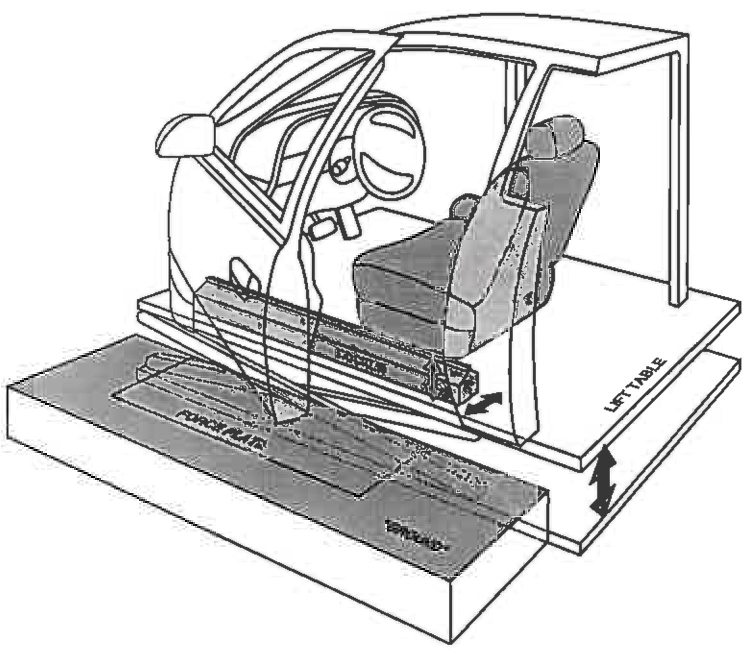

Figure 3. Schematic drawing of ingress/egress seating buck.

The simulated "ground" of the I/E test facility was raised above the laboratory floor to allow the top surface of a six-axis force platform to be placed at ground level, and to accommodate the rocker adjustment mechanism while achieving the desired SgRP-to-ground distances. A video camera was positioned to provide an oblique overhead recording of each ingress/egress task performed during subject testing. Subject forces applied to the seat and steering wheel during testing were measured by a six-axis load platform and a six-axis load cell, placed between the seat and the vehicle frame, and between the steering wheel and the steering column, respectively. In addition to visual observations during testing, subject leg and foot contacts with the rocker panel were detected by an accelerometer mounted to the bottom of the rocker panel. All force and accelerometer signals were amplified and analog low-pass filtered at 33-Hz cutoff, using an eighth order hybrid elliptical filter. Filtered signals were digitized by a National Instruments A/D board in a Pentium PC. Data acquisition and display were managed using the LabView software package.

The hinge mechanism illustrated in Figure 4a and shown in Figure 4b was designed and implemented to allow simulation of three types of door-hinge mechanisms and associated door-swing movements. A structure mounted rigidly to the vehicle frame, just forward of the upper A-pillar, incorporates three separate sets of bushings within which heavy-duty pins can pivot. A beam, welded to the driver door, extends forward and contains three bushings that align with the bushing sets in the vehicle-mounted structure. Each set of bushings is oriented somewhat differently relative to the vehicle in order to achieve the desired door-swing movements.

By inserting a heavy-duty pin in any one of the three aligned sets of bushings, one of three types of door hinge was simulated during subject testing. In position A, the production Taurus hinge was simulated to produce the standard pivot-hinge-type door motion. With the pin in position B, a four-bar type hinge (labeled 4-bar(a)) was simulated, such that the front and upper parts of the door moved laterally as the door was swung open. The pin in position C simulated a second four-bar hinge (labeled 4-bar(b)) that produced more extreme lateral movements of the door as it opened. Hinge center locations and angles are shown in Table 1.

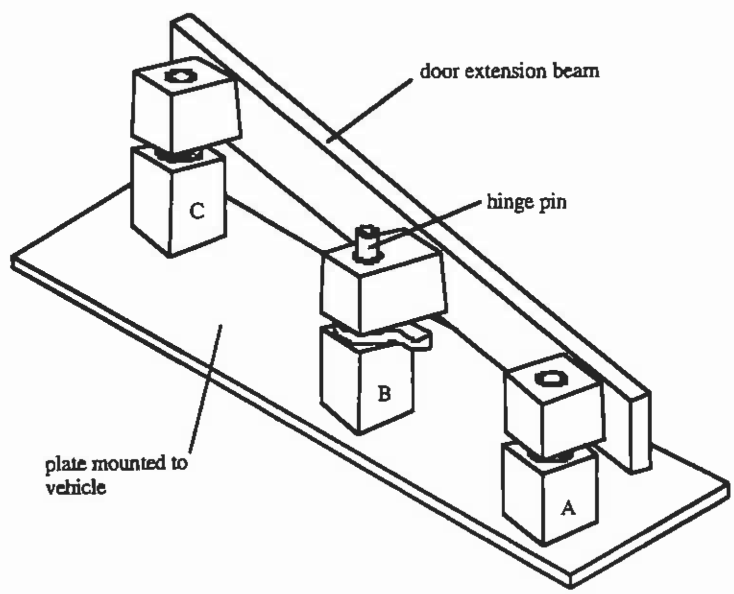

Figure 4a. Drawing of three-pivot mechanism used to simulate production and four-bar mechanism door hinge scenarios. The drawing shows the hinge pin in the "B" position.

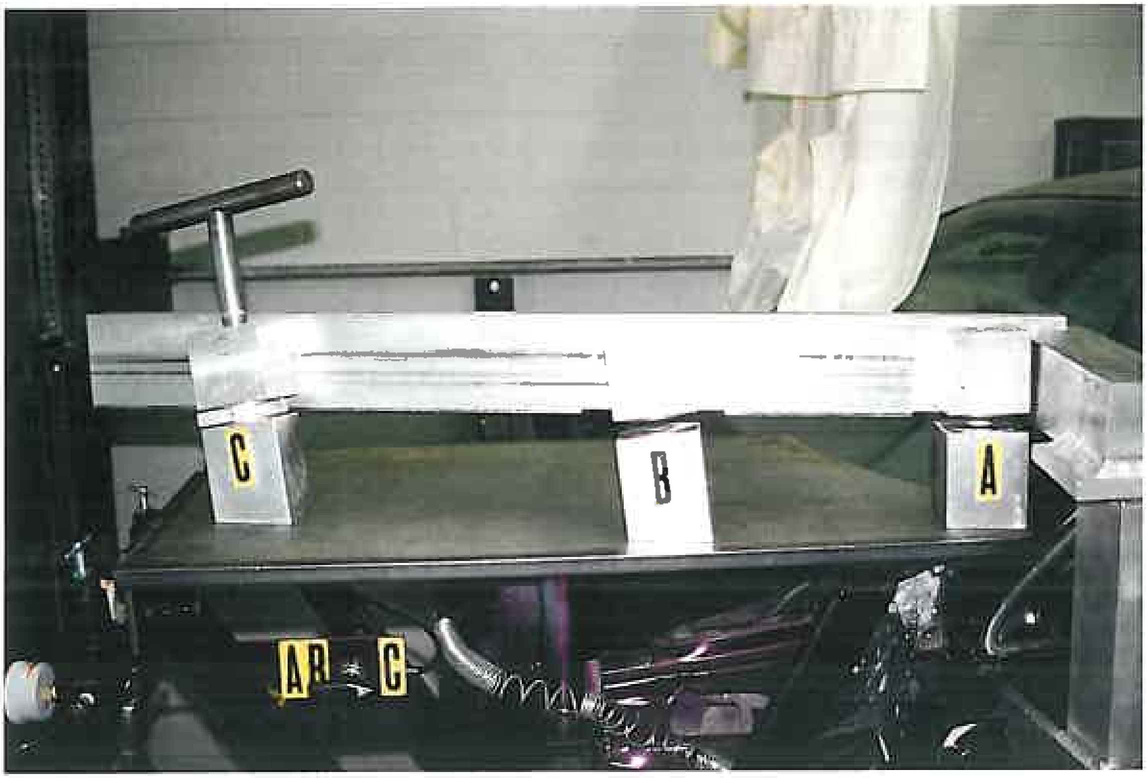

Figure 4b. Three-pivot mechanism attached to ingress/egress test buck used to simulate production and four-bar mechanism door hinge scenarios (See Appendix H for additional photos).

Table 1
Hinge Center Locations and Hinge Pin Orientations

	Pivot Center re Production Hinge (mm)		Hinge Pin Angle (degrees re horizontal)	
Hinge Pin	Forward of Production	Inward of Production	Rear Projection	Side Projection
A pivot	0	0	91.5 up and forward	87.3 up to pass. side
B 4-bar(a)	316	20	96.3 up and forward	82.5 up to pass. side
C 4-bar(b)	718	120	97.6 up and forward	80.9 up to pass. side

Due to the mass of the door and hinge mechanism, the door seemed heavier (i.e., more resistant to opening) when the pivot was in positions B and C, than in position A. In order to better equalize the "feel" of the door under the different hinge conditions, some countermeasures were taken. A pneumatic piston was mounted between the hinge mechanism and the vehicle to provide some lift to the door. The pressure inside the piston was set higher for the simulated four-bar (b) condition than the other two. Also, an elastic cord was attached from the wall to an eye-bolt on the exterior of the door. This cord helped pull the door open in the four-bar (b) condition. Prior to Phase-1 testing, the piston pressure and elastic cord were set for the two 4-bar hinge conditions to achieve door-opening conditions that were subjectively perceived[1] by the investigators to produce comparable door-opening forces in the B and C pivot locations as in the A pivot location.

[2]It was subsequently determined that the actual door-opening forces for the three conditions were not equivalent, even after further adjustment of the elastic cord and pressures in Phase-2 testing.

4.2 Subject-Sampling Strategy

In order to investigate if and how subject factors, such as stature, age, weight, and gender affect the perception and performance of ingress and/or egress, an exploratory subject sampling design was used. The desired and actual makeup of subject groups are shown in Tables 2a and 2b.

The subject groups in Tables 2a and 2b essentially form a one-factor-at-a-time design for three factors. Comparisons of results across Groups 1 through 3 provide information about the effect of stature on subjects' response to vehicle variables in the I/E task. Comparison of results for Group 2 to those for Group 4 provides information about the effect of age, and comparison of Group-2 to Group-5 results provides information about the effect of weight. Interactions between subject variables are not tested in this design. If such interactions do exist, they are expected to be small in magnitude and difficult to implement in practice. Thus, information about subject-variable interactions was sacrificed in order to learn more about the main effects with a small sample.

Table 2a
Desired Subject-Group Characteristics

Group # (Name)	Gender	n	Stature Range (mm)	Stature Range (in)	Age Range (yrs)	Weight Range (lb)
1 (Short)	Female	6	1534-1581	60.4 - 62.2	20-35	118.5-130.5
2 (Mid)	Male Female	3 3	1656-1712	65.2 - 67.4	20-35	152.5-164 134-149
3 (Tall)	Male	6	1791-1844	70.5 - 72.6	20-35	174.8-190.9
4 (Elderly)	Male Female	3 3	1656-1712	65.2 - 67.4	>65	152.5-164 134-149
5 (Heavy)	Male Female	3 3	1656-1713	65.2 - 67.4	20-35	>180.5 >171.5

Table 2b
Actual Subject-Group Characteristics

Group #	Gender	n	Stature (mm)		Age (yrs)		Weight (lb)	
(Name)			Mean	Range	Mean	Range	Mean	Range
Group 1 (Short)	Female	6	1542.5	1532-1575	23.8	20-36	118.4	89-144
Group 2 (Mid)	Male Female	3 3	1678.8	1650-1710	27.0	20-32	153.2 137.2	145-155 127-152
Group 3 (Tall)	Male	6	1804.3	1783-1823	24.2	19-28	162.3	134-194
Group 4 (Elderly)	Male Female	3 3	1645.5	1617-1673	68.2	63-74	159.8 132.5	133-187 114-145
Group 5 (Heavy)	Male Female	2 4	1683.7	1631-1722	25.2	21-30	184.0 179.5	173-195 174-186
All Subjects		30	1671.0	1532-1823	33.7	19-74	150.6	89-195

4.3. Experimental Design

The experimental design was divided into two phases. The full sample of thirty subjects participated in Phase 1, in which each subject completed a series of trials over the course of three days of testing (about four hours total). The trials were divided into two types based on the response required of the subject. The first type of testing completed by each subject is *Paired Comparisons* testing, in which the subject was presented with two vehicle configurations in succession and asked to decide which one was easier to enter and exit. The second type of testing used is *Ratings* testing, in which the subject was presented with a single vehicle configuration and asked to rate the difficulty of the ingress and egress tasks separately on a seven-point scale.

The second phase of the experiment was conducted after all subjects had completed Phase-1 testing. It included a small set of Paired Comparisons trials to test more directly for the effect of the door-hinge type on ease of entry and exit. Four subjects from each of the five subject groups returned for a fourth session to complete Phase 2.

Paired Comparisons Protocol

Each Paired Comparisons trial consisted of two vehicle configurations. While the subject was out of the test area, the buck was set to the first configuration, and the subject was asked to get in and out at their own pace. After exiting the buck, the subject again stepped out of the test area and was asked to try to keep the experience of the first condition in mind. The buck was reconfigured to the second condition of the pair, the subject returned to the test area and entered and exited the buck. The subject then indicated verbally which configuration was easier to enter and exit, the first or the second. The response was recorded, including any subject comments or experimenter observations, and the subject left the test area while the buck was reconfigured for the next trial. Forms used to record subject responses and comments are included in Appendix A.

Ratings Protocol

Each Ratings trial consisted of one vehicle configuration. While the subject was out of the test area, the buck was configured for that trial. The subject returned to the test area and entered the buck. While the subject remained in the vehicle, he/she rated the difficulty of entry on a seven-point scale. In addition, the subject was asked to write any comments he/she might have about the experience of entering the vehicle in that configuration, and to indicate whether the configuration was unacceptably difficult. The subject then exited the buck and stepped out of the test area to sit at a table, where he/she completed the same form for egress. The buck was then configured for the next trial while the subject waited outside the test area. The forms used by subjects for Ratings testing are included in Appendix B.

Phase-1 Testing: Session 1

During subject recruitment and prior to the first ingress/egress trial, subjects were only told that they were participating in a study of vehicle design and driver seating. The first session of Phase-1 testing included initial test/measurement activities plus a short set of experimental trials. (See Appendix C for forms and instructions.) The subject was asked to sign a preliminary consent form, and to fill out a health questionnaire and a driving-habits questionnaire. The anthropometric measurements listed in Table 3 were then taken, and the subject was shown the test buck, which had been previously adjusted to a nominal set of doorway and door-hinge conditions that included the production pivot door hinge, the mid-seat-to-ground distance (575 mm), the low rocker height (25 mm above AHP), and the low rocker width (400 mm to seat centerline), as specified by condition C2 in Table 4.

The subject was instructed to open the door, enter the vehicle, shut the door, adjust the seat fore-aft position and seatback angle to comfortable positions, and then exit the vehicle and close the door. Figure 5 shows a subject undergoing I/E testing.

Table 3
Anthropometric Measurements

Stature w/ and w/o shoes
Weight w/o shoes
Erect sitting height
Eye height (sitting erect)
Sitting shoulder height
Buttock-knee length
Knee height
Popliteal height
Shoulder breadth
Shoulder-elbow length
Elbow-hand length
Buttock-popliteal length
Foot length

This initial trial was considered representative of the subject's "natural" entry/exit strategy for nominal ingress/egress conditions. Upon completion of this initial trial, the subject was informed that the specific purpose of the study was to investigate driver ingress and egress issues, and was told in greater detail what would be required. If the subject agreed to continue with testing, a second consent form was signed and the subject proceeded with Paired Comparisons testing.

Figure 5. Subject exiting ingress/egress buck.

Phase-1 Testing: Sessions 2 and 3

Two types of testing were conducted in Sessions 2 and 3. Subjects first participated in Paired Comparisons testing, followed by Ratings testing. After testing was completed on the third test day, subjects filled out the two final questionnaires, included in Appendix D, that were designed to determine the factors that subjects considered important to their perception of the difficulty of ingress and egress. The first questionnaire lists a number of possible influences on subjects' judgments of acceptability for ingress, such as "bumping leg on rocker panel" or "having to adjust the seat position after entry," and the second questionnaire lists possible influences on the acceptability of egress. Many of the questions overlap, but the lists are not identical. Subjects indicated on a seven-point scale the extent to which each influence was important in their judgments.

Test conditions

Ratings Testing. Table 4 gives the conditions that were presented in the Ratings portion of the testing. The levels of each variable were chosen to span a broad range, as might be seen in production vehicles. James (1985) measured rocker width from the outer edge of the seat cushion to the outer edge of the rocker panel, so it is not possible to directly compare values (in this study lateral rocker width is measured from the seat centerline). However, the distances from the outer edge of the seat to the outer edge of the rocker panel in this study fall near and above the upper end of the range used by James (1985). Assuming that the seat used by James was similar in width to the Taurus seat used in this study, the results of this study extend James' conditions to more difficult rocker widths. Although James (1985) found a strong linear relationship between rocker width and acceptance level, three levels of rocker width were used in the current study in order to gather more information about the linearity of the effect of rocker width.

The range of seat-to-ground distances used in this study spans the entire range tested by James (1985) and Loczi (1993) and extends slightly above Loczi's range and below James' range. James (1985) found a U-shaped relationship between acceptance level and seat-to-ground distance, so it was considered important to test at three levels of this variable. Based on his results, the lowest and highest level in this study (450 mm and 700 mm) should fall on either side of the peak, and the middle level (575 mm) should fall near the peak.

Two rocker heights relative to heel surface were used in this study. The low height of 25 mm above AHP is below that used by James' (1985), while the high height of 100 mm above AHP is the same as the highest value used by James (note, however, that this high position is slightly lower than the Taurus production height of about 115 mm above AHP). James found only a weak relationship between rocker height and acceptance level, and acceptance was generally high, even at a rocker height of 100 mm. Thus, rocker height was not expected to affect ingress/egress difficulty as strongly as the other variables, and a third level of this variable was considered unnecessary.

As indicated previously, the buck was designed to allow three door-hinge conditions. In addition, a fourth door condition was created by swinging the door completely open, thereby simulating a sliding door that is completely out of the way during ingress and egress.

Table 4
Conditions for Ratings Testing

Condition ID	Door Hinge S	Rocker Width (mm) W	Seat-to-Ground (mm) Hz	Rocker Height (mm) D	Paired Compar./ Repeatability	Condition Set
C1	Pivot	400	450	100	PC	α
C2*	Pivot	400	575	25	PC/R	α/β
C3	Pivot	500	450	25	PC	β
C4	Pivot	500	575	100	PC	β
C5	4-bar (a)	400	450	25		β
C6	4-bar (a)	400	575	100		α
C7	4-bar (a)	500	450	100		α
C8	4-bar (a)	500	575	25		β
C9	4-bar (b)	400	450	100		α
C10	4-bar (b)	400	575	25		α
C11	4-bar (b)	500	450	25		β
C12	4-bar (b)	500	575	100		β
C13	None	400	450	25		β
C14	None	400	575	100		β
C15	None	500	450	100		α
C16	None	500	575	25		α
C17	Pivot	400	450	25	PC	β
C18	Pivot	400	575	100	PC	β
C19	Pivot	450	450	25		β
C20	Pivot	450	450	100		α
C21	Pivot	450	575	25		α
C22	Pivot	450	575	100		β
C23	Pivot	500	450	100	PC	α
C24	Pivot	500	575	25	PC	α
C25	Pivot	400	700	25		α
C26	Pivot	400	700	100		β
C27	Pivot	450	700	25		β
C28	Pivot	450	700	100		α
C29	Pivot	500	700	25		α
C30	Pivot	500	700	100	PC/R	α/β

W = seat C/L to outside edge of rocker.
Hz = SgRP to ground vertical distance.
D = top of rocker to AHP vertical distance.
* Initial test condition.
Shading indicates conditions for full-factorial design with production pivot door hinge.

The conditions in Table 4 comprise a half fraction of a 4x2x2x2 design [4 door conditions (S) by 2 rocker widths (W) by 2 seat-to-ground heights (H) by 2 rocker heights (D)], labeled C1 through C16. The conditions also includce a full-factorial combination of WxHxD (3x3x2) using a standard pivot hinge, indicated by shading in Table 4. Four conditions are common to both of these subdesigns (C1 through C4), resulting in thirty unique configurations that were used in Ratings testing in the second and third Phase-1 test sessions, with fifteen conditions tested each day.

Two conditions (C2 and C30) were repeated in each session to investigate the reliability of ratings both within a session and across sessions (i.e., days). Each of the repeated conditions was presented four times, three times in one session and once in the other. Thus, the total number of Ratings conditions presented each day was eighteen.

The last column in Table 4 shows the assignment of Ratings conditions to session sets, labeled α and β. Each set includes half of the conditions plus four repeated conditions. Within each set of trials, the repeatability trials were presented in a fixed order, and the other trials were randomized to fill the remaining slots. For example, in Set α, C2 was presented first, ninth, and last (eighteenth), and C30 was presented second. All other conditions in Set α were in a different order (within the remaining slots) for each subject. In Set β, C30 was presented first, ninth, and last, and C2 was presented seventeenth. Half the subjects were tested with Set α in Session 2, and half were tested with Set β in Session 2.

Paired Comparisons Testing. Table 5 shows the subset of conditions that were used for the Paired Comparisons portion of Phase-1 testing. The nine Paired Comparisons conditions comprise a 2x2x2 factorial combination of a WxHxD (rocker width by seat-to-ground by rocker height) plus one "difficult" condition at the highest level of seat-to-ground distance.

Table 5
Conditions for Paired Comparisons Testing

Condition	Door Style S	Rocker Width W	Seat-to-Ground Hz	Rocker Height D
C17	Pivot	400	450	25
C1	Pivot	400	450	100
C2	Pivot	400	575	25
C18	Pivot	400	575	100
C3	Pivot	500	450	25
C23	Pivot	500	450	100
C24	Pivot	500	575	25
C4	Pivot	500	575	100
C30	Pivot	500	700	100

Ideally, all possible pairs of conditions should be used in a Paired Comparisons study. This way, all of the available methods for hypothesis testing and estimation of the underlying order can be used. However, within the time and budget limitations of this study, only a subset of the possible comparisons could be run. One way to limit the number of comparisons is to limit the number of conditions. This was done by using only the nine conditions in Table 5. The second way to limit the number of comparisons is to use a carefully selected subset of *pairs*. In this case, eighteen of the possible thirty-six pairs were selected. These pairs were spread over three days of testing with six pairs presented each day.

Table 6 shows the sets of condition pairs for which each subject was tested on the different days. As indicated, the pairs were divided into three sets. Subjects were tested for one complete set of pairs on each day of testing. One-third of the subjects evaluated Set A in Session 1, one-third evaluated Set B in Session 1, and one-third evaluated Set C in Session 1. The assignment of condition sets to days for each subject followed a Latin Square design.[2] Within each set, the order of pairs was randomized.

Table 6
Condition Pairings

Condition Set	FIRST CONDITION		SECOND CONDITION	
	Condition ID	W/Hz/D	Condition ID	W/Hz/D
Set A	C1	400/450/100	C23	500/450/100
	C3	500/450/25	C18	400/575/100
	C17	400/450/25	C2	400/575/25
	C17	400/450/25	C3	500/450/25
	C18	400/575/100	C4	500/575/100
	C30	500/700/100	C24	500/575/25
Set B	C2	400/575/25	C18	400/575/100
	C3	500/450/25	C1	400/450/100
	C4	500/575/100	C1	400/450/100
	C23	500/450/100	C2	400/575/25
	C24	500/575/25	C4	500/575/100
	C30	500/700/100	C17	400/450/25
Set C	C1	400/450/100	C17	400/450/25
	C2	400/575/25	C24	500/575/25
	C4	500/575/100	C30	500/700/100
	C18	400/575/100	C23	500/450/100
	C23	500/450/100	C30	500/700/100
	C24	500/575/25	C3	500/450/25

Other Measures

In addition to the behavioral responses collected for each subject, a number of objective measures were also obtained during each ingress/egress task. These include six-degree-of-freedom force-time measurements on the "ground" outside the vehicle, on the seat, and on the steering wheel. Also, contact with the rocker panel was recorded, both by an accelerometer on the rocker panel and by experimenter observation. Signals from the load platforms and rocker panel acceleromter were input to a dedicated PC computer using a set of National Instruments (NI) model SCXI-1121 four-channel amplifiers, an NI model SCXI-1141 eight-channel elliptical filters, and an NI AT-M10-64E-3 data acquisition

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[3]A Latin Square is a standard method of balancing order between groups of subjects. One-third of subjects evaluated Condition Set A on Day 1, Set B on Day 2, and Set C on Day 3. One-third of subjects evaluated Condition Sets B, C, and A on Days 1,2, and 3, respectively, and one-third of subjects evaluated Condition Sets in the order C, A, and finally B. In this way, each set is tested on each day, balancing any fatigue or learning effects across the conditions.

board. LabView software was configured to acquire and display the data as shown in Figure 6 for review by the investigator prior to data storage and selection of the next test configuration.

Figure 6. Display of force signals on computer screen using LabView.

These measures were used to investigate the relationship between subject ratings of ingress and egress with physical measures of effort and body contact. In particular, it was desired to determine if physical measures are related to subjective acceptability of ingress/egress since establishing a physical or objective indicator of ingress/egress ratings would offer significant advantages to future ingress/egress studies. In addition, even if no single physical measure captures acceptability, the pattern of results across different measures might provide useful information about the mechanisms by which the ingress/egress task is made easy or difficult.

Phase-2 Testing

The second phase of the experiment included a small set of Paired Comparisons trials to test directly for the effect of the door-hinge type on ease of entry and exit. Four subjects from each of the five subject groups returned for a fourth session to complete Phase 2.

Test Protocol and Conditions

Phase-2 testing was completed in one session of approximately 45 minutes. Subject anthropometry had already been collected, and subjects were already familiar with test procedures.

Table 7 shows the subset of conditions used for Phase-2 Paired Comparisons testing. The eight Paired Comparisons conditions comprise a 4x2 factorial combination of door-hinge by seat-to-ground distance with fixed rocker width (500 mm) and height (100 mm). The rocker width and height were chosen to represent difficult ingress/egress conditions for which the door-hinge type would be most likely to make a difference. The seat-to-ground distance was varied because the relative difficulty of different seat-to-ground distances was expected to vary with subject anthropometry.

As in Phase-1 testing, a subset of the possible pairs was used. Specifically, all six possible pairs of conditions P1 through P4 were tested, and all six possible pairs of conditions P5 through P8 were tested. The twelve pairs were presented in a different random order for each subject.

Table 7
Conditions for Paired Comparisons Testing in Phase 2

Condition	Door Style S	Rocker Width (mm) W	Seat-to-Ground (mm) Hz	Rocker Height (mm) D
P1	No door	500	450	100
P2	Pivot	500	450	100
P3	4-bar (a)	500	450	100
P4	4-bar (b)	500	450	100
P5	No door	500	575	100
P6	Pivot	500	575	100
P7	4-bar (a)	500	575	100
P8	4-bar (b)	500	575	100

5.0 STUDY RESULTS

5.1 Phase-1 Results

Generating Scale Scores from Paired Comparisons Data

The Paired Comparisons method is used in conjunction with a mathematical procedure to assign scores on an arbitrary scale to a set of "objects" or in this case, conditions, based on simple comparisons between pairs of the objects (conditions). Details of the scoring procedure are given in Appendix E. The advantage of the method is that people are good at comparing two things, and so it combines a task that subjects can perform reliably and accurately with a mathematical procedure to assign numbers to each condition so they can be compared. The numbers that are assigned indicate the ranking of the conditions and the relative differences between them. For example, if condition A gets a score of 1, B gets a score of 3, and C gets a score of 7, it is legitimate to conclude that C is preferred to B by twice as much as B is preferred to A. Although scores cannot be compared across subjects (e.g., a score of 1 for Subject 1 is not necessarily the same as a score of 1 for Subject 2), all the relevant analyses are done within subjects, so the conclusions are not affected by that restriction.

Analysis of Paired Comparisons (PC) Scores

The Paired Comparisons conditions (excluding the extreme Hz=700 condition) form a 2x2x2 (rocker width x Hz x rocker height) factorial. The scores from the eight conditions by five subject groups were analyzed using ANOVA. Results are graphed in Figure 7, along with the mean score for C30, the most extreme condition. Note that the bars for all factor levels except Hz=700 are the mean of four scores per subject. The Hz=700 bar is made up of only one score per subject, which involved the highest level of the other two variables. As a result, the difference between the tallest Hz bar and the other two Hz bars is accentuated. In addition, because Paired Comparisons scores are arbitrary up to a linear transformation, no values are given on the vertical axis. Absolute scores cannot be interpreted, but differences between scores can.

As shown, there are significant main effects of rocker width ($F(1,25)=24.201$, $p<.0001$) and Hz ($F(1,25)=12.957$, $p=.0014$; *lowest two levels only*). There is also a significant two-way interaction between seat-to-ground distance and rocker height ($p=.0041$), such that the high rocker (to AHP) was preferred to the low rocker only at Hz=450 mm. This interaction is not graphed because it does not make mechanistic sense and is not confirmed by the Ratings data.

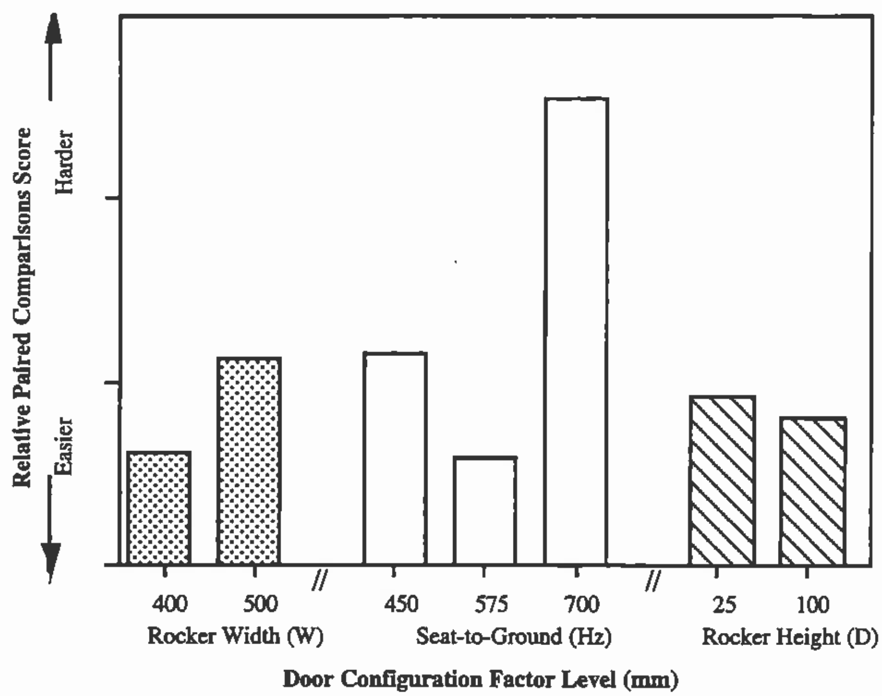

Figure 7. Mean Paired Comparison scores by factor level. Note that each subject sees four conditions with each factor level except the highest Hz. This level appears in only one Paired Comparisons condition. The main effects of rocker width and seat-to-ground distance (2 levels only) are significant.

Consistency of Paired Comparisons

One measure of consistency of Paired Comparisons judgments has been discussed above in the context of stability of scale scores. Another way to look at consistency is to look for triads of conditions in which each is compared to the other. If a subject has a clear preference ordering for those conditions, his/her comparisons between the three should be transitive. That is, if the subject judges condition A to be easier than B, and B to be easier than C, then when A and C are compared, A should be judged easier than C. Each subject saw three such triads of conditions. Judgments were transitive in 89% of cases across all subjects and all triads, which is significantly better than chance by a Chi-Square test.

Analysis of Ratings, Pivot-Hinge Subdesign

The Ratings conditions contain two subdesigns, plus repeatability conditions, so these sets of conditions were separated for analysis purposes. For repeated conditions, the mean rating was used in analyses of the effects of doorway factors. The first subdesign was a full factorial using only the pivot hinge (production door). A 5x3x3x2x2 (subject group by rocker width x Hz x rocker height x ingress or egress task) repeated-measures ANOVA was performed on these data.

As seen in Figure 8, the main effects of subject group and task are significant, with the elderly group rating all conditions as more difficult on average than all the other groups. In addition, the egress task is rated as more difficult on average.

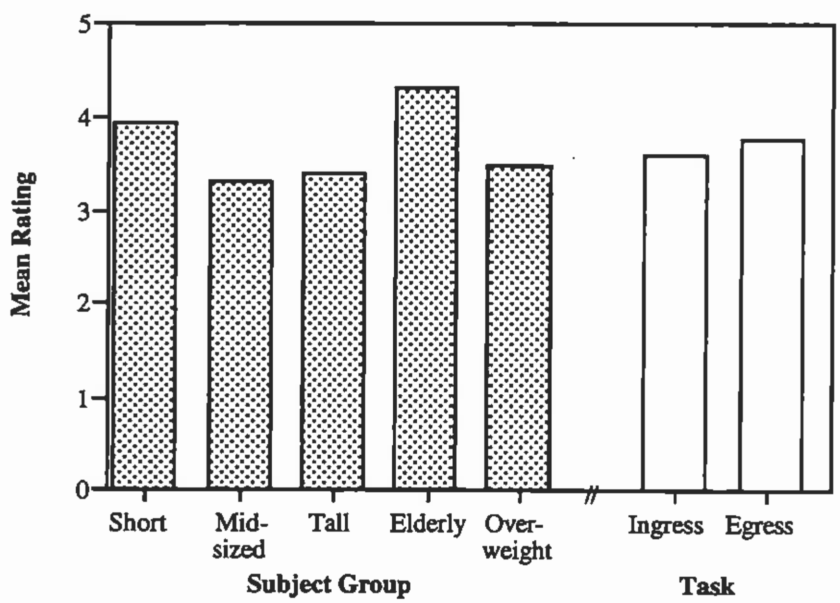

Figure 8. Main effects of subject and task factors on rated ease of ingress/egress (averaged across vehicle factors).

Mean combined ingress and egress ratings for rocker width, seat-to-ground, and rocker height conditions are graphed in Figure 9. The main effects of rocker width and seat-to-ground distance are significant. Increasing rocker width increases the perceived difficulty of ingress and egress, and seat-to-ground distance produces the highest difficulty ratings at the highest height, and the lowest difficulty ratings at the middle height. This U-shaped function has been seen in previous work (James 1985).

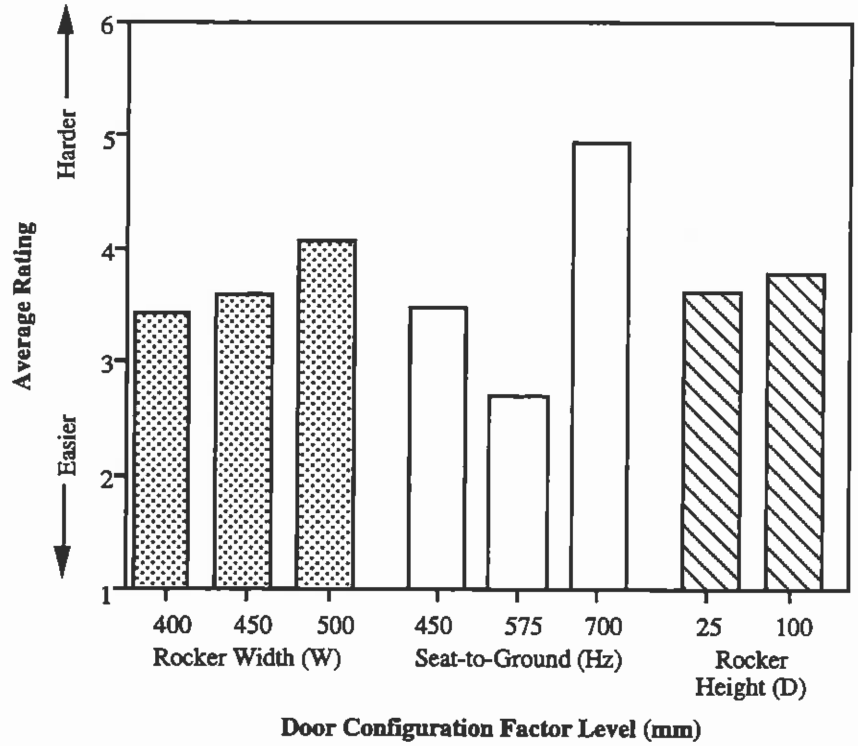

Figure 9. Main effects of vehicle factors on rated ease of ingress/egress (averaged across task and subject group).

The main effects, however, do not give a complete picture since there are a number of interactions of the vehicle configuration with task and subject variables. For example, the effect of rocker width changed with the task (i.e., ingress vs. egress) and with the subject group (the three-way interaction is not significant). The interaction between task and rocker width is graphed in Figure 10. The increasing difficulty as rocker width increases is more pronounced for the egress task as compared to the ingress task. Note, however, that the total range of these ratings is very small (less than one rating point).

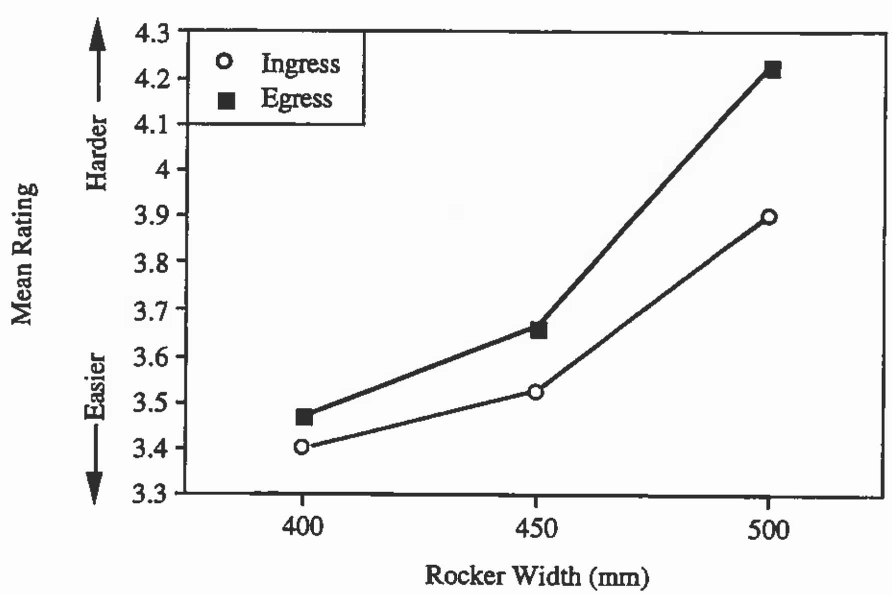

Figure 10. Mean subject ratings for rocker width by ingress/egress tasks.

The interaction between subject group and rocker width is depicted in Figure 11. The interaction appears to result primarily from the overweight group, which rates the middle rocker width as slightly easier, on average, than the other two. However, the reason for this difference is not immediately obvious, and the size of the difference is small.

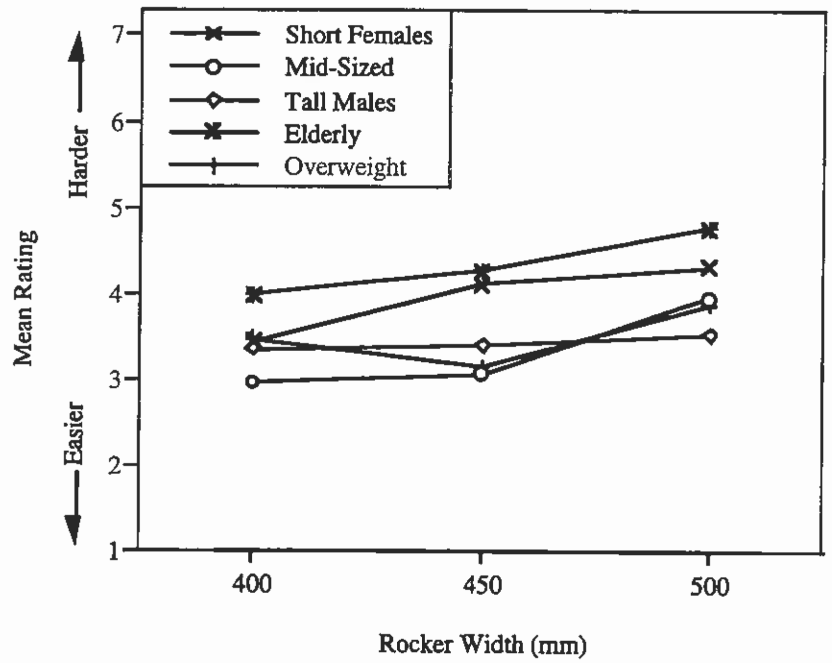

Figure 11. Mean subject ratings for rocker width by subject group.

As shown in Figures 12 and 13, the effect of seat-to-ground distance interacted with both task and subject group individually. Figure 12 shows that at the lowest Hz (450 mm), the egress task was rated as significantly more difficult than the ingress task. At the highest Hz, both tasks were rated as the most difficult of the three Hz levels, but egress was slightly (though not significantly) easier than ingress.

The subject group by Hz interaction, shown in Figure 13, resulted primarily from the tall-male group Rating the highest Hz condition (700 mm) as being the same difficulty as the lowest (450 mm). All other groups rated the 700-mm Hz as significantly more difficult. The short-female group rated the middle Hz (575 mm) the same level of difficulty as difficult as the lowest Hz (450 mm). Of the five groups, the short females and the elderly gave the highest difficulty Ratings for the 700-mm seat-to-ground distance.

Figure 14 shows average rating as a function of seat-to-ground distance and rocker width. Contrary to expectations, Hz and rocker width did not interact significantly in their effect on ingress or egress ratings. The effect of each factor is additive, making the wide rocker/high seat-to-ground a difficult combination, but not more difficult than the sum of the two individual effects, as was hypothesized.

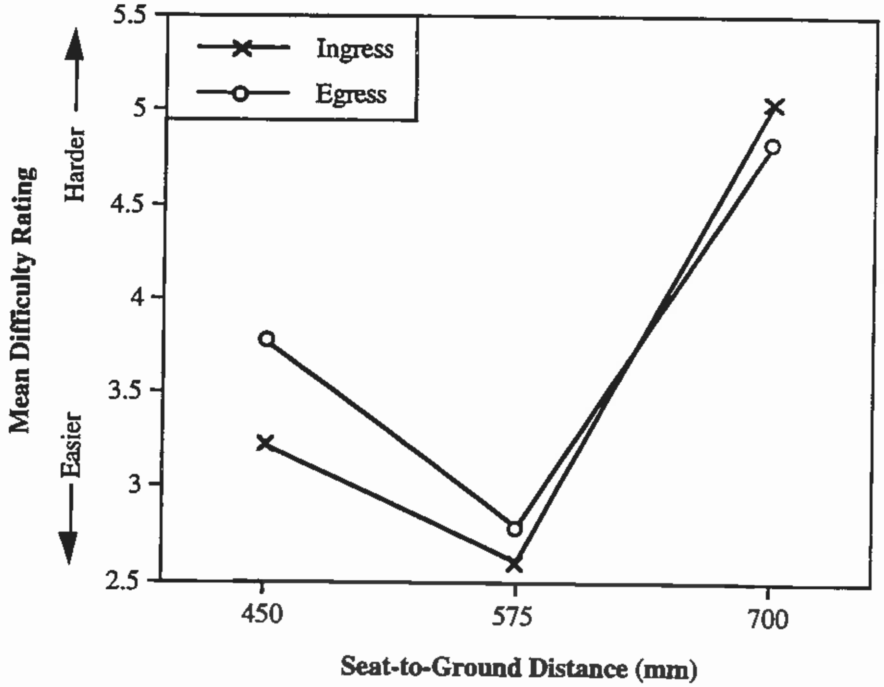

Figure 12. Mean subject ratings for ingress and egress by seat-to-ground distance.

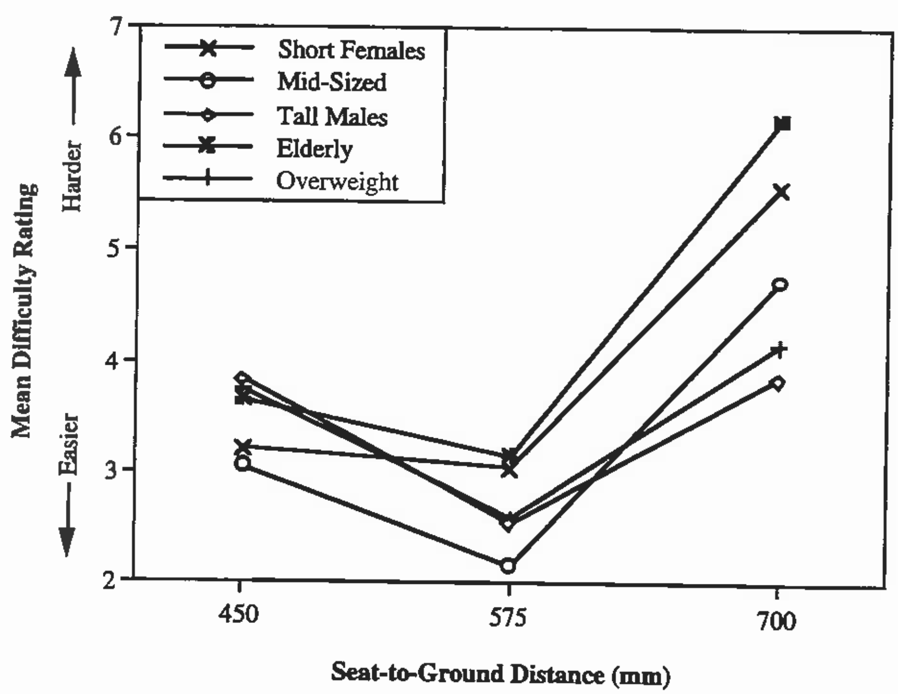

Figure 13. Mean subject ratings for seat-to-ground distance by subject group.

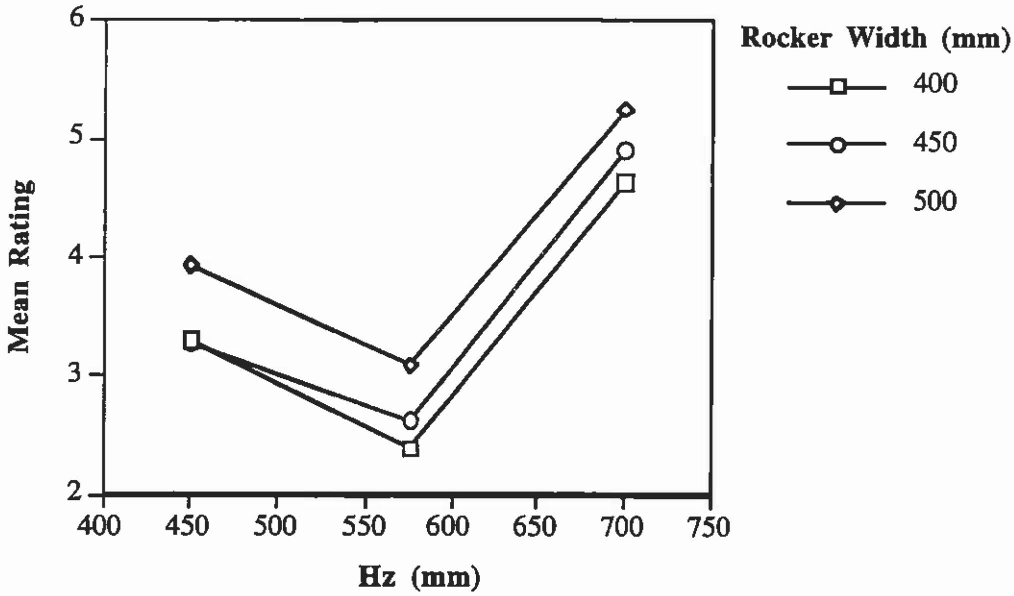

Figure 14. Mean subject Ratings for seat-to-ground distance by rocker width. Interaction is not significant.

Analysis of Ratings: Door-Type Subdesign

A 5x2x4x2x2 ANOVA (subject group x task x door type x rocker width x Hz) was performed on the difficulty ratings. For each subject, eight of the thirty-two observations included in this analysis (all those using a pivot hinge) overlapped with those included in the pivot-only analysis. The pattern of results involving factors other than the door-hinge type are similar to those found in the previous analysis, with the exception of subject-group effects. In this analysis, no effects or interactions involving subject group are significant. This probably occurred because the highest Hz condition was not included in this subdesign. Subject groups differed the most in their ratings of conditions with the highest Hz in the pivot-only subdesign (see Figure 13), leading to the significant interaction between subject group and Hz described above. Without that condition, the groups are less differentiated and the effect does not reach significance in this analysis. All other significant main effects and interactions found in the pivot-only analysis are also significant in the door-hinge analysis with the same pattern of mean ratings.

In addition, the effect of door-hinge type is significant. However, the pattern of results, illustrated in Figure 15, is not as expected. The no-door (or wide-open) condition was rated easiest and was rated significantly easier than the mean of the other three conditions in post-hoc analyses. The pivot-hinge door was rated as easier than either of the simulated 4-bar hinges, though post-hoc analysis showed the difference is only marginally significant. The fact that the four-bar hinges were rated as the most difficult of the four is unexpected. Although subjects were instructed to consider only the entry/exit task in their ratings, not the difficulty of opening the door itself, it is possible that differences in the weight of the door, which existed even after adding the bungee cord and pneumatic piston for the four-bar hinge conditions, influenced subject ratings.

When the door was wide open, subjects did not open or close the door, making that part of the task easier. James (1985) found that elderly and disabled subjects preferred to have the door available to lean on when entering and exiting, but there is no indication of this pattern in the data. Not only is the interaction between door type and subject group not significant in the current study, but, of the five subject groups, the elderly group gave the second lowest (easiest) rating in the no-door condition and the highest (most difficult) rating in each of the other door conditions, on average.

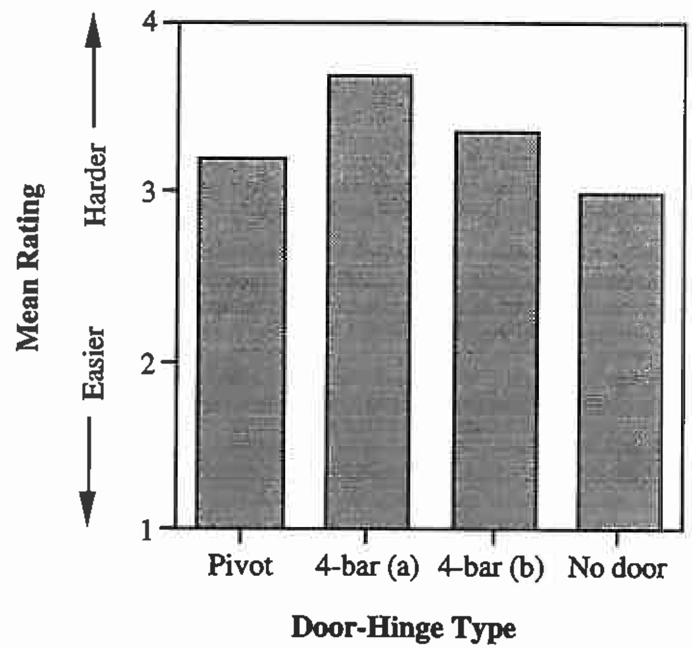

Figure 15. Effect of door-hinge type on ratings.

Analysis of Acceptability Ratings

In addition to rating ease of ingress and egress in each condition, subjects were asked to check a box if the configuration was unacceptably difficult. In general, subjects rarely checked the box. Only 3.4% of conditions were judged unacceptable on ingress and 4.4% on egress. However, there were differences between conditions and subject groups in judgments of acceptability. As illustrated in Figure 16, the elderly group used the "unacceptable" category twice as often as the short, midsized and overweight groups. Tall males did not rate any conditions unacceptable for either ingress or egress. The highest seat-to-ground distance produced the most "unacceptable" ratings of any level of any factor. As shown in Figure 17, subjects rated conditions with the highest Hz unacceptable for ingress 11.5% of the time and unacceptable for egress 14.4% of the time.

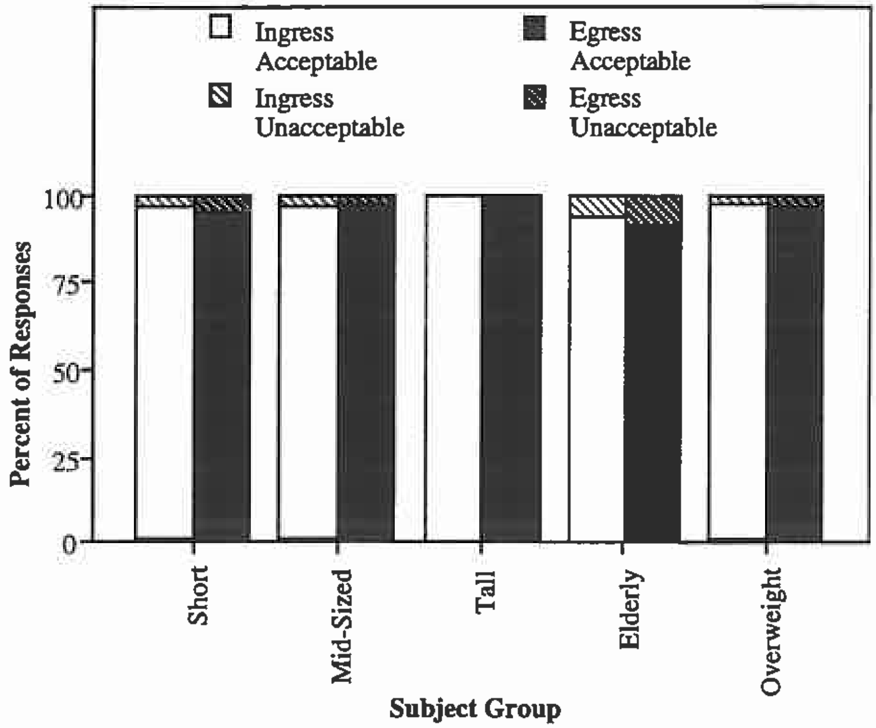

Figure 16. Acceptability ratings expressed as a percent of total trials, as a function of subject group.

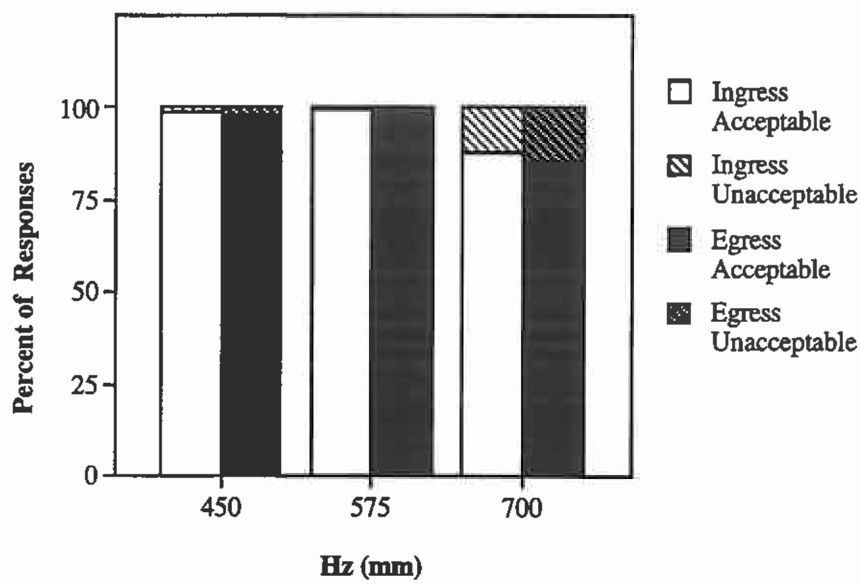

Figure 17. Acceptability ratings expressed as a percent of total trials, as a function of seat-to-ground distance.

Analysis of Repeated Trials

Repeated trials were analyzed to look for any consistent drift in the course of a test session or across days. One measure of variability is the standard deviation of repeated trials for each subject. The mean within-subject standard deviation for repetitions within days is 0.66 ratings points, and the mean between-day standard deviation is 0.40. The lower between-day standard deviation is probably an artifact of the small number of trials used to calculate each standard deviation measure. Given that even a random perturbation in ratings must result in a change of at least one unit, a standard deviation of less than one is small.

An alternative method of measuring variability is to look at the maximum difference between any two ratings of the same condition. For example, if a subject gave ratings of 1, 1, and 2 to the easily repeated condition on three different trials, the maximum difference is 1. Across subjects, the mean of this measure is 1.2 for within-day repetitions and 1.2 for between-day repetitions. Thus, individual ratings of repeatability conditions may change slightly from one occurrence to the next, but the total amount of variation is quite small.

Finally, analysis of variance showed no consistent drift in ratings across subjects. Thus, the Ratings are consistent both across and within days, and ratings from trials scattered over two sessions can be used together without undue concern about the effects of fatigue or experience on judgments.

Comparison of Ratings and Paired Comparisons Scores

The ranking of the nine Paired Comparisons conditions, generated by Paired Comparisons scores were compared to the rankings of the same conditions, generated by Ratings. Because the ratings were done separately for ingress and egress, while the Paired Comparisons reflected the whole task, several methods were used to try to match the two. Paired Comparison rankings were compared to Ratings rankings produced by ingress only, egress only, mean of ingress and egress, maximum of ingress and egress, and minimum of ingress and egress. Spearman's rho was calculated for each subject, and the highest mean correlation was 0.49 for the maximum method.

This level of correlation for individuals is not as high as was hoped, but several factors may have contributed to the reduced correlation. First, it is difficult to match separate ratings for ingress and egress to a single Paired Comparisons score for the whole task. For any given subject on any given trial, the Paired Comparisons response might be influenced most by some aspect of ingress, egress, or both. None of the formulas used can account for changing influences. Second, with only seven choices for Ratings scores, there are many ties between different conditions. When there are often ties in the Ratings and only rarely ties in the Paired Comparisons scores, the correlation between rankings of conditions will be correspondingly lower.

Although the Ratings and Paired Comparisons are only moderately related for individuals, the picture looks different when they are compared *across* individuals. The ranks produced by the mean scale score and the ranks produced by mean Ratings (by the same five methods) are correlated, and the values range from 0.867 to 0.917. Thus, the ordering of conditions across subjects is very similar between the two methods of data collection.

The Paired Comparisons judgment is a relatively easy one for people to make, so it represents a kind of standard for the Ratings to measure up to. Although the correlations across conditions for individual subjects are lower than expected, the correlation for the aggregated values is high, and the pattern of results with respect to factor effects is very similar. In addition, the Ratings are highly repeatable. Thus, the Ratings are considered valid measures of subjects' responses to the vehicle conditions. However, the relationship between Ratings and Paired Comparisons is still not well understood for individual subjects.

Analysis of Force Data

A significant quantity of force-time history data was collected during subject testing but a comprehensive analysis of these data in conjunction with the subjective results is beyond the scope of this project. The approach taken for the analysis conducted to date was to identify several force and time parameters that, *a priori,* were hypothesized to affect the perception of ease or difficulty of the ingress or egress tasks, and that might, therefore, provide insight into subjects' judgments of task difficulty. These parameters were analyzed with respect to vehicle factors and subjective ratings. The parameters chosen are described in Table 8 and illustrated in Figure 18. Only the forces from the Ratings testing have been analyzed at this time.

The two upper curves in Figure 18 show samples of signals from the ground transducer, with the topmost curve showing the vertical force and the curve below showing the resultant horizontal force. The third and fourth traces are the lateral and vertical signals from the seat transducer. The fifth trace is the resultant force on the steering wheel. Due to mechanical coupling between the steering wheel and the rest of the buck, vibrations were introduced into the wheel load cell when the door was opened or closed. In the absence of other criteria, the onset of these vibrations was used as a time mark. Time of ingress was computed as the time from the door opening before ingress to the door closing after ingress (T_1 to T_2). Time of egress was computed from door opening to door closing (T_3 to T_4). Table 9 provides a description of the various events displayed in the traces of Figure 18.

Table 8
Selected Parameters from Force-Time Histories

Variable Name	Variable Symbol	Description	Calculation
Time of Ingress Time of Egress	T_i T_e	Time from opening of car door to closing of car door; used by Koester and Hamilton (1994) as measure of I/E difficulty	$T_2 - T_1$ from F_{wheel} $T_4 - T_3$ from T_{wheel}
First and second peak vertical ground forces, Egress	FG_{zei} FG_{zes}	Peak vertical ground forces during egress; indication of how "hard" subject comes down on ground	Maximum FG_z from first and second egress ground contact excluding peak from stepping off force platform
Horizontal Ground Force, Egress	FGH_e	Peak horizontal ground force during egress; large values indication of risk of slipping	Maximum horizontal resultant ground force (X and Y) force
Seat Vertical Force, Ingress	FS_{zi}	Peak vertical seat force during ingress; indication of how gently subject lowers him/herself to seat	Maximum FS_z from time of initial seat contact to door closing
Seat Horizontal Force, Ingress	FS_{hi}	Peak horizontal force during ingress; indication of amount of adjusting subject needs to do to slide into position	Maximum lateral seat force (X and Y) from time of initial seat contact to door opening for egress
Force on Steering Wheel, Ingress/Egress	FW_i FW_e	Peak force on wheel during ingress and egress; indicates use of wheel to aid I/E	Peak resultant wheel force signal, above a threshold, not attributed to door opening/closing
Rocker Contact	RC_i RC_e	Yes or no, if rocker was contacted during ingress/egress	Accelerometer signal, above a threshold, not attributed to door opening/closing

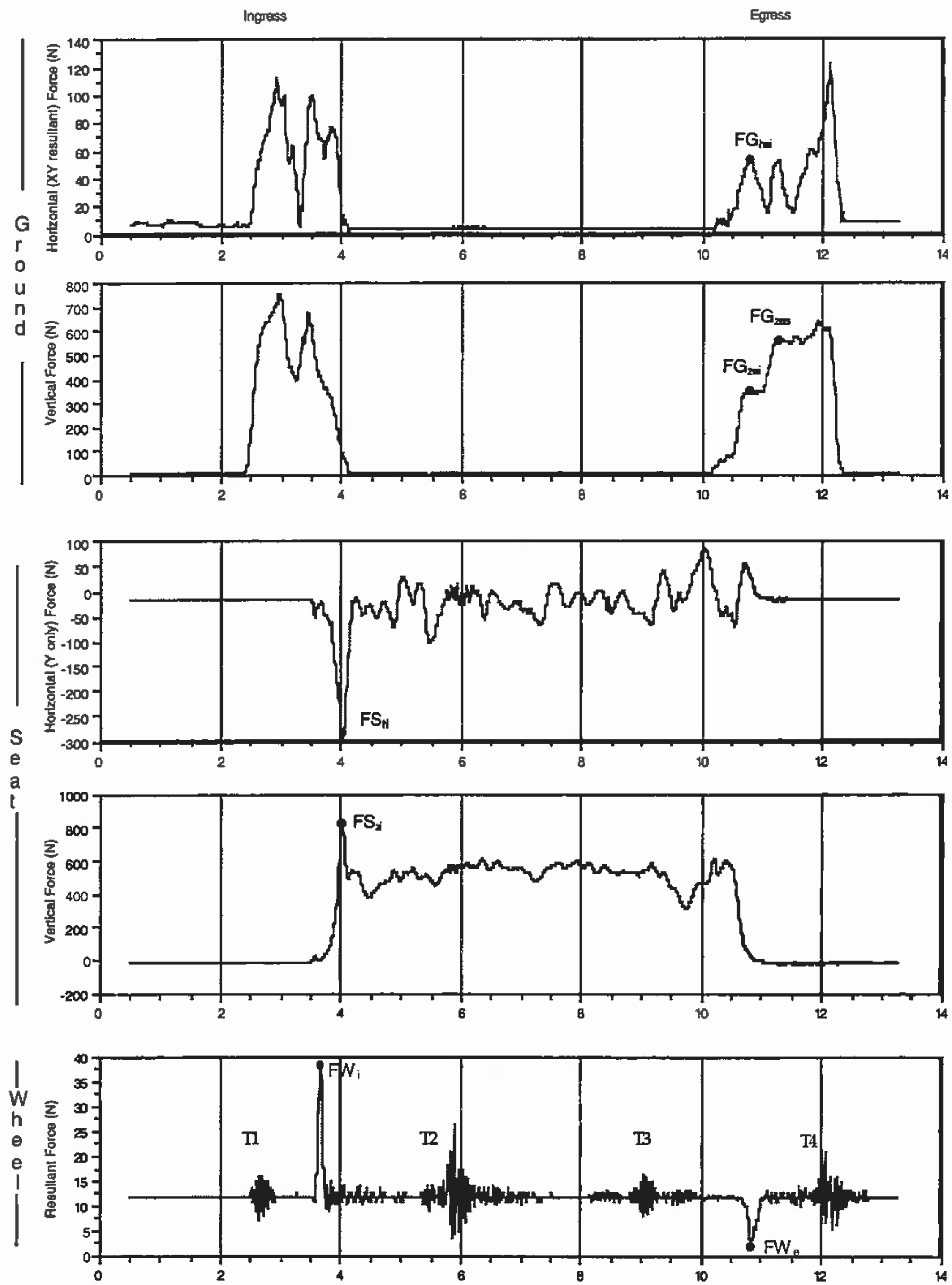

Figure 18. Sample force-time histories with parameters illustrated.
Refer to Table 8 for interpretation of abbreviations of parameters.

Table 9
Subject Events Corresponding to Force Signals at
Various Times in the Ingress/Egress Task

TIME	EVENT
	Ingress Starts
2.4	subject first steps onto ground platform
2.5	subject opens door
3 - 3.5	subject brings second foot onto ground platform
3.5	subject grabs steering wheel; first contact with seat
3.5 - 4	subject lowers onto seat; takes weight off foot on ground
4.0	peak vertical force on seat
4.1	subjects weight totally off ground
4.1- 5.5	subject adjusts weight on seat
5.5	subject closes door
6-8.5	subject sits relatively still
	Egress Starts
8.8	subject open door for egress
9 - 10	subject swings foot out
10.0	subject's foot contacts ground
10.6	subject's foot firmly on ground and subject grabs steering wheel
10.6	subject puts more weight on legs and less weight on seat
10.8	all of subject's weight off seat; second peak of vertical ground force
12.0	subject closes door
12.5	subject step off ground platform

Two ANOVAs were conducted on each force parameter, except rocker contact, following the same structure as the analyses of subjective ratings. Rocker contact was analyzed as a categorical variable. For the analysis of T_i and T_e, only three door conditions were included in the analysis, since in the no-door condition, there is no indication in the force-time history where to begin or end timing. Table 10 summarizes the significant effects found in each analysis.

Rocker contact was measured using an accelerometer on the bottom of the rocker panel. However, the accelerometer was relatively sensitive and sometimes registered very low forces when there was no actual contact. Because of this, rocker contact was recoded as a categorical variable. A cutoff reading was chosen to distinguish between noise and actual contact. All readings below the cutoff were labeled "no contact" and all readings at or above the cutoff were labeled "rocker contact." Loglinear modeling was used to analyze these data. However, there is no relationship between rocker contact and any vehicle or subject factor for either ingress or egress.

Table 10
Significant Effects of Vehicle Factors on Force Parameters

Variable Name	Variable Abbreviation	Independent Factor				
		Subject Group	Door Type	Rocker Width	Hz	Rocker Height
Time for ingress	T_i			**	**	
Time for egress	T_e		**		**	
Peak horiz. force on seat during ingress	FS_{hi}					
Peak vert. force on seat during ingress	FS_{zi}	*	*		*	
Peak resultant force on wheel on ingress	FW_i				*	
Init. peak vert. force on ground on egress	FG_{zei}		*		*	
2nd peak vert. force on ground on egress	FG_{zes}	**			*	
Peak horiz. force on ground during egress	FG_{he}			**		
Peak force on wheel during egress	FW_e		**		**	
Rocker contact on ingress	RC_i					
Rocker contact on egress	RC_e					

* $p<.01$
** $p<.001$

Appendix E contains histograms of each of the force parameters listed in Table 10. These histograms are collapsed across subjects and conditions, so they give a broad picture of the range of possible values for these parameters. The shapes of the histograms do not necessarily reflect the distributions of forces in real-world ingress/egress situations because neither the subject pool nor the conditions in this experiment are representative of the distribution of subjects and vehicle configurations in the real world.

Appendix F contains tables listing the mean values of force parameters by subject group, door-hinge type, rocker width, and seat-to-ground distance. Significant effects of subject group on force parameters are shown in Figure 19. Subject groups differ primarily on vertical force parameters, due to heavier weights of tall and overweight subjects.

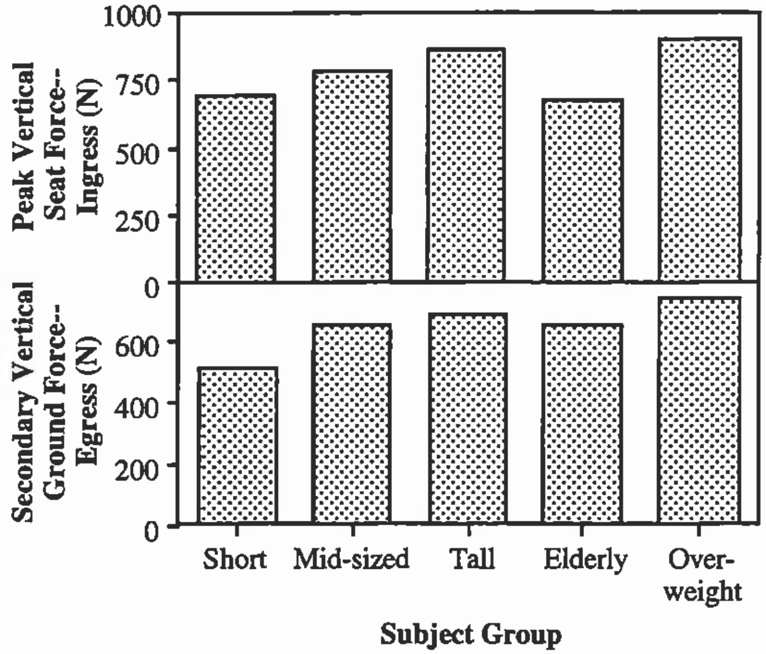

Figure 19. Mean peak vertical force on seat and ground, respectively, during ingress and egress by subject group.

Significant effects of door-hinge type on force and time parameters are graphed in Figure 20. Door-hinge type significantly affected time of egress, force on the wheel during egress, and vertical force on the seat and ground. Time to egress increased for the four-bar hinge conditions over the production door pivot and was greater for the more extreme four-bar hinge (pivot C) than for the pivot-B four-bar hinge. As mentioned earlier, this may have been caused by the increased weight of the door when the hinge point was farther away from the opening.

Vertical force on the seat during ingress and force on the wheel on egress were significantly greater for the conditions when the door was present. When the door was not used, both of these forces were low. On egress, the initial peak force on the ground was higher in the no-door condition relative to the three door-present conditions. It is possible that when the door is not in the way, subjects change to a strategy that makes less use of the steering wheel but results in a more forceful first step on the ground (without the steering wheel to take up some of that force).

Significant effects of rocker width on force and time parameters are graphed in Figure 21. Rocker width significantly influenced time for ingress and horizontal ground force on egress. Increases in rocker width increased the time taken for entry. The widest rocker panel produced higher horizontal ground force on egress.

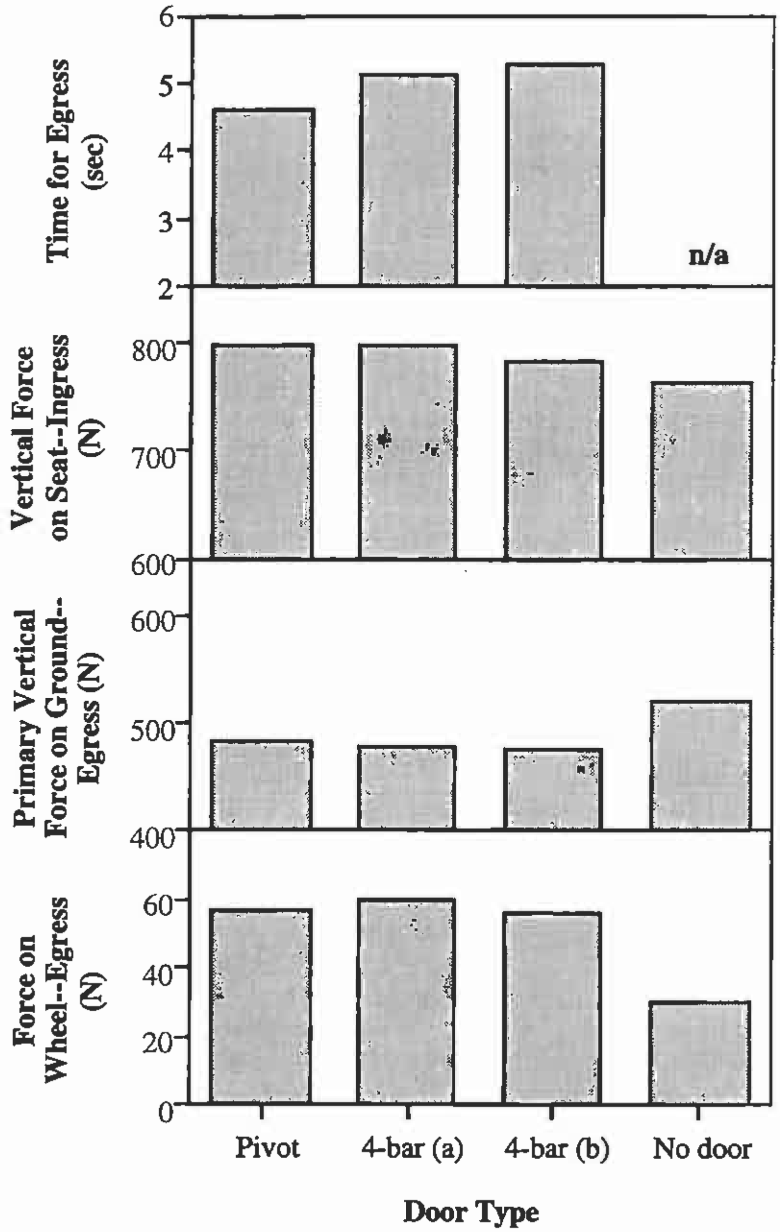

Figure 20. Mean force level by door-hinge type.

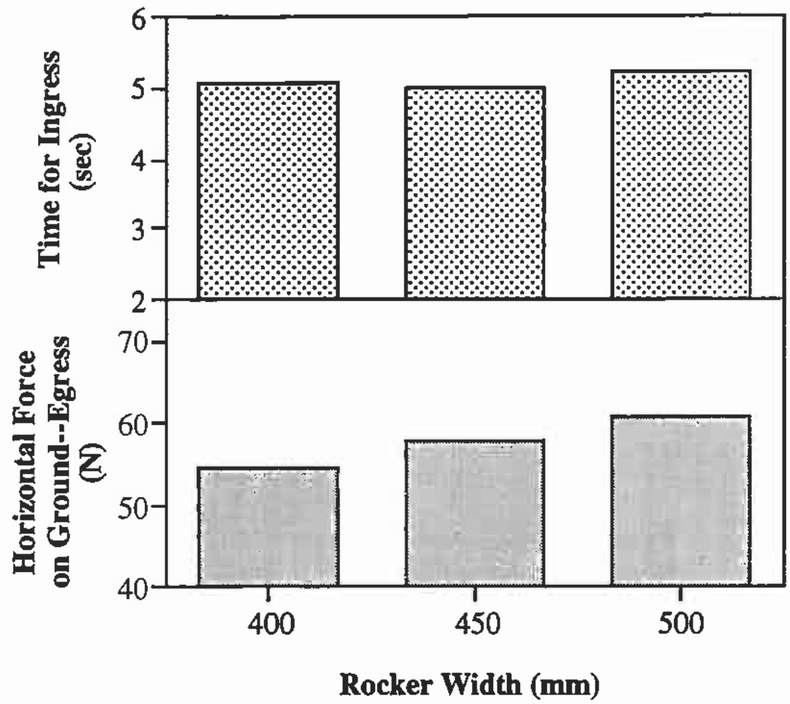

Figure 21. Mean force level by rocker width.

Significant effects of seat-to-ground distance on force and time parameters are graphed in Figure 22. Seat-to-ground distance significantly influenced all the force parameters except horizontal seat and ground forces. Time to ingress and egress are directly related to the rocker width and inversely related to the difficulty ratings. That is, the slowest condition (Hz=700 mm) is also the most difficult condition and the fastest condition (Hz=575 mm) is also the easiest condition. Peak steering-wheel force for both ingress and egress decreased as seat-to-ground distance (Hz) increased, suggesting that subjects use the steering wheel more to get in or out of a low vehicle. In general, peak vertical force on the seat decreased with increasing Hz, but second peak vertical force on the ground on egress increased with increasing Hz. However, as shown in Figure 23, for the initial peak, the effect was very different for different subject groups. For the overweight, elderly, and short groups, the initial peak was highest at the highest Hz and lowest at the lowest Hz. For the tall group, initial peak vertical force on the ground actually decreased at the highest Hz, suggesting that, for these subjects, the high Hz allowed them to step gently out of the vehicle, rather than coming down hard as do the smaller subjects (other than those in the midsized group).

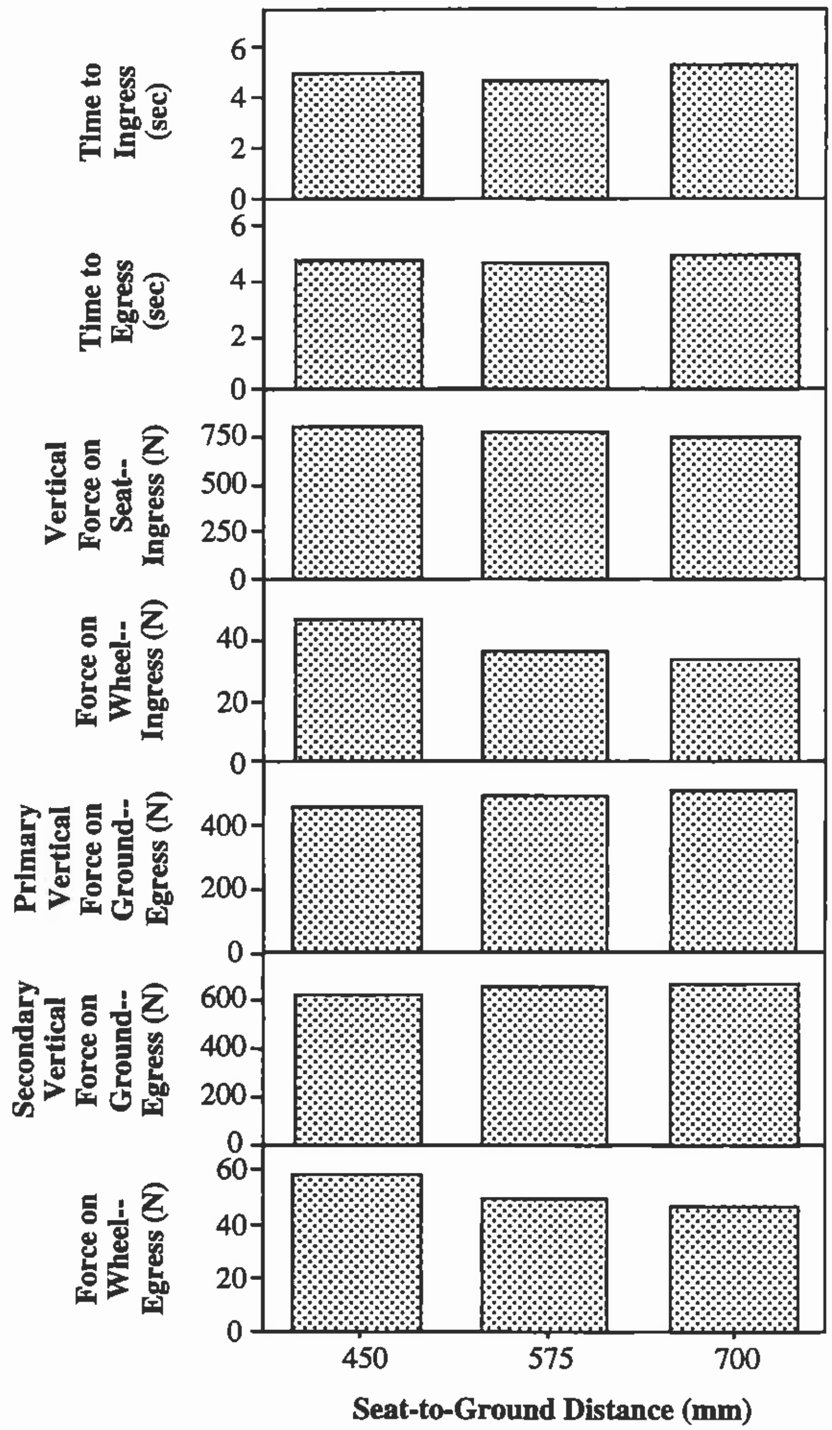

Figure 22. Mean force level by seat-to-ground distance.

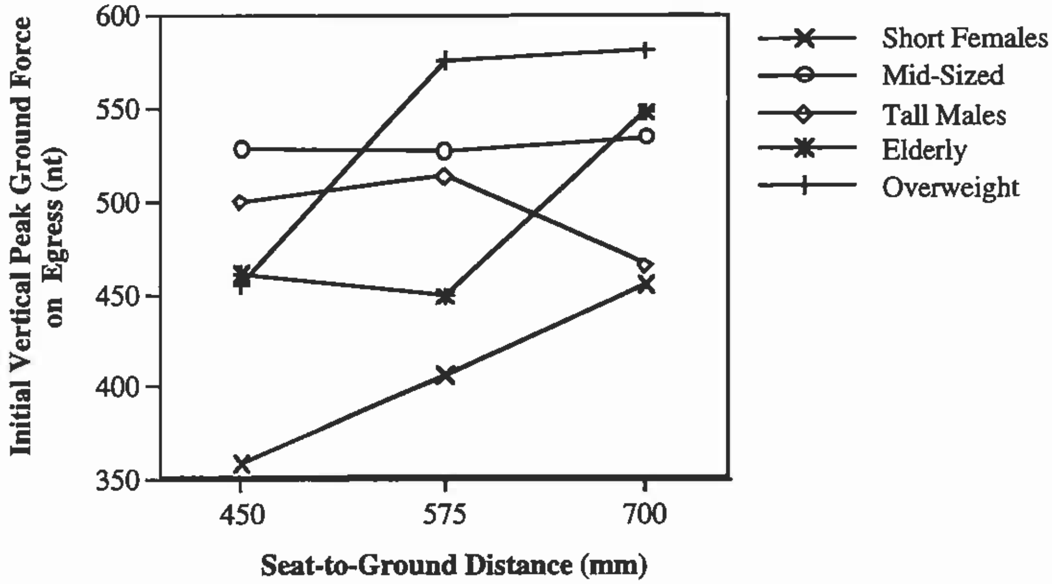

Figure 23. Initial peak vertical ground force during egress by seat-to-ground distance for different subject groups.

Relationships Between Forces, Times, and Ratings

Each of the force-time parameters was correlated with subjective rating of either ingress or egress (as appropriate for the parameter) for each subject. Time to ingress and time to egress were the most highly correlated with subjective difficulty, but the mean values of r were 0.207 and 0.185, respectively. Obviously, the linear relationships between ratings and forces and times are extremely weak. Although the effects of vehicle variables on force parameters make mechanistic sense, subjects' considerations in making ratings are not directly linked to any single aspect of the force-time histories or to times for ingress or egress.

When ratings and forces are averaged across subjects before being compared, the relationships are somewhat stronger. Time for ingress and time for egress are correlated with mean rating at 0.37 and 0.34, respectively. Horizontal force on the seat on ingress is correlated with mean ratings at 0.52, the highest level of any of the force parameters.

Rocker Contact

As previoulsly indicated, contact of the subject's leg or foot with the rocker panel was determined by investigator observation as well as by an accelerometer mounted to the rocker panel. The signal from the accelerometer was used to indicate door opening and closing times for measures of ingresss and egress timing, and, if the accelerometer signal exceeded a certain threshold value between the times of door opening and closing, the occurence of rocker contact was indicated. While a thorough comparison of investigator -observed rocker contacts with contacts determined by the accelerometer signal exceeding a threshold level has not yet been made, the relative counts of rocker contacts obtained by the two methods appear to be in general agreement for the different subject groups and conditions.

Using these accelerometer-detected contacts, a 2x5 ANOVA (contact x subject group) was conducted on the ingress ratings and another on the egress ratings. The results show no significant effect of leg or foot contact with the rocker panel on the rated difficulty of either ingress or egress. However, the frequency of rocker contact did differ among subject groups and across conditions. For some factors, such as rocker width, the changes in frequency of rocker contact are consistent with overall effects on rated difficulty. However, for others, such as Hz, the effects are not consistent with difficulty ratings. As a result, there is no consistent relationship between rocker contact and rated difficulty, and the data do not support the hypothesis that rocker contact is a primary determinant of difficulty of ingress/egress.

Table 11 shows rocker contact on ingress and egress for different subject groups. On ingress, the short and elderly groups contacted the rocker least often, and the overweight group most often. On egress, the short group also contacted the rocker the least often, and the tall group had the most rocker contacts. For both ingress and egress, the effect of subject group is statistically significant. It is not clear why the short subjects had the least contacts on both ingress and egress than the other groups, but it may be related to the strategy used. For example, on egress, a number of the short subjects turned in the seat prior to exiting with both legs simultaneously, instead of putting the left foot and leg out first. This may account for the very low number of rocker contacts on egress for the short subjects. It is also possible that there were more rocker contacts for the short subjects, but that many of the contacts produced accelerometer signals below the established threshold.

Table 11
Rocker Contact by Subject Group

Subject Group	Number of I/E Observations	Percent of Observations with Detected Rocker Contact	
		Ingress	Egress
Short	180	76%	48%
Mid-sized	180	87%	71%
Tall	180	89%	80%
Elderly	180	81%	71%
Overweight	180	92%	73%

Table 12 shows rocker contact on ingress and egress for different rocker widths. For both ingress and egress, contact frequency increases significantly with increasing rocker width, although there are more contacts overall on ingress than egress.

Table 12
Rocker Contact by Rocker Width

Rocker Width (mm)	Number of I/E Observations	Percent of Observations with Detected Rocker Contact	
		Ingress	Egress
400	360	81%	59%
450	180	83%	68%
500	360	89%	79%

Table 13 shows rocker contact frequencies for different seat-to-ground distances. In general, seat-to-ground distance has minimal effect on the frequency of rocker contact. On egress, there were no differences between conditions, and on ingress, the observed decrease in contact frequency with increasing seat-to-ground distance is only marginally significant.

Table 13
Rocker Contact by Seat-to-Ground Distance

Seat-to-Ground Distance (mm)	Number of I/E Observations	Percent of Observations with Detected Rocker Contact	
		Ingress	Egress
450	360	88%	67%
575	360	84%	70%
750	180	81%	68%

Analysis of Final Questionnaire Responses

Appendix D includes the complete text of the questions that were asked at the completion of testing as well as overall mean responses for each question, broken down by subject group. Table 14 summarizes the mean values by listing the factors that were judged most important and least important by each subject group. In general, vehicle height (either too high or too low) was of greatest concern to all subjects. Bumping the rocker panel appears frequently in Table 14 as well. On the other hand, subjects were generally not concerned about having to adjust their seat position in order to enter or exit the vehicle.

To look at subject-group and task differences, analysis of variance was used to analyze each question on the final questionnaire. Subject groups differed in their rating of the importance of some of the items. For example, the elderly group rated bumping the steering wheel as more important than did the other groups. On ingress, bumping the rocker panel was of moderate concern to most subject groups. However, on egress, short and midsized subjects rated bumping the rocker panel to be of greater concern than the other groups. Significant effects are noted in Table D.1 of Appendix D.

Table 14
Mean Responses to Final Questionnaire Items by Subject Group

Importance of Factor	Subject Group				
	Short	Mid-sized	Tall	Elderly	Overweight
First	Seat-to-ground too high	Seat-to-ground too high	Seat-to-ground too low	Seat-to-ground too high	Seat-to-ground too low
Second	Bump rocker panel on egress	Bump rocker panel on egress	Seat-to-ground too high	Bump wheel (ingress and egress)	Rotate body (ingress and egress
Third	Lower self gently on ingress	Rotate body (ingress and egress)	Bump rocker panel on ingress	Seat-to-ground too low	Seat-to-ground too high
Least	Adjust seat position on egress	Bend for roof rail on ingress	Adjust seat position on ingress	Adjust tilt wheel	Adjust seat position on egress

5.2 Phase-2 Test Results: Door Hinge Paired Comparisons Testing

Phase-2 testing was conducted in order to focus on the effect of the door hinge. Paired Comparisons was used for this purpose, and a complete set of pairs of door-hinge types was tested at two levels of Hz. The two lower levels were chosen because four-bar hinges were not expected to be used on sport-utility and other high-Hz vehicles.

Because of the unexpected results from Phase-1 Paired Comparisons testing with regard to door-hinge effects, additional efforts were made prior to Phase-2 testing to equalize the door opening force for the different pivot conditions. Door-opening force-displacement was subsequently characterized for each hinge condition by measuring the pull force on the door handle required to move (i.e., open) the door at four different positions of door opening. Figure 24 shows the results of these measurements, which indicate that some differences in door opening force for the different hinge conditions were still present after these additional adjustments.

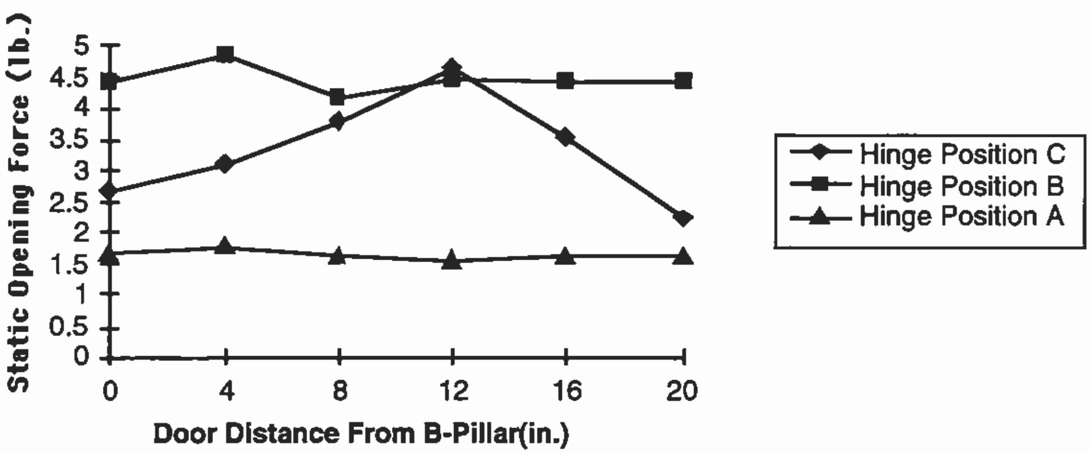

Figure 24. Static door opening force versus distance of door edge from B-Pillar.

Scale scores for each group of four door types (grouped by Hz level) were calculated and log-transformed as in Phase 1. A 5x4 ANOVA (subject group x door type) was conducted on each group of scores separately. For the high Hz, there are no significant effects or interactions. However, for the low Hz level, subjects significantly preferred the pivot and open doors to either of the four-bar hinges. As noted before, differences in door weight may have influenced subject's judgments, even with instructions to ignore these differences and with attempts to better equalize the weights for Phase 2. Results for the low Hz level are graphed in Figure 25, and for the high Hz level in Figure 26. Because there were no comparisons between different Hz levels, the mean scores shown in Figures 25 and 26 cannot be compared to each other.

Even though the preference for door types was not as expected, it is interesting that door-hinge type only made a difference at the low level of Hz. From the results of Phase 1, it is clear that 575 mm is significantly preferred over 450 mm. It is possible that the easier vehicle height makes the differences between door styles irrelevant, but that when the vehicle height is low enough make getting in and out more difficult, differences between door-opening features and force levels become more noticeable and relevant.

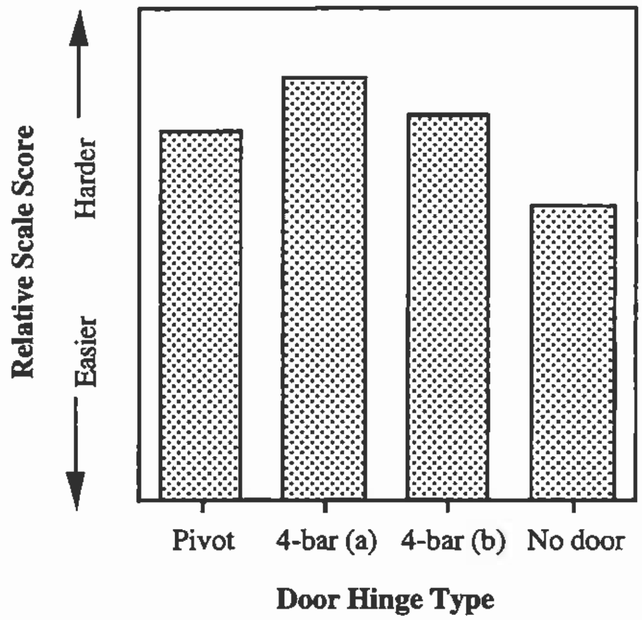

Figure 25. Paired Comparisons scores for different door hinge types at Hz=450 mm.

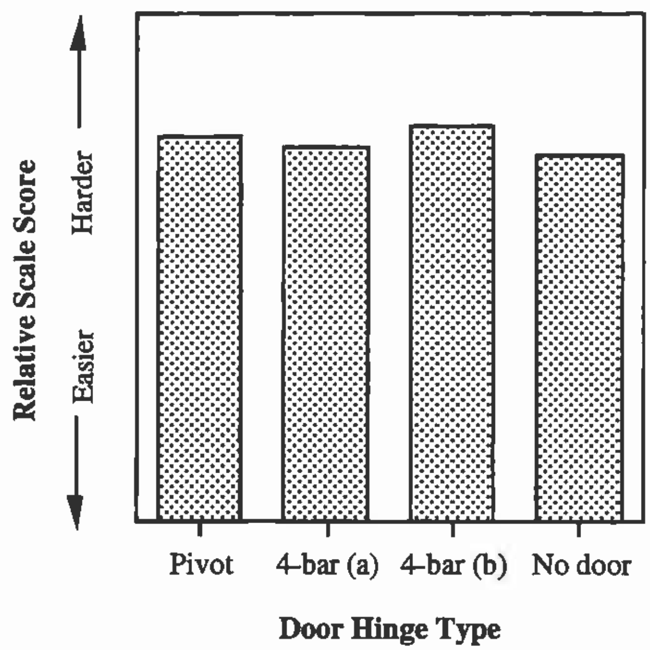

Figure 26. Paired Comparisons scores for different door hinge types at Hz=575 mm.

6.0 SUMMARY AND DISCUSSION

In section 3, the study objectives were described. The results presented above are discussed below in the context of these objectives.

6.1 Comparison of Data-Collection Methods

Two data-collection methods were used in this study—Paired Comparisons and Ratings. *A priori*, Paired Comparisons is considered a more accurate and sensitive method of determining preferences because it involves direct comparisons of two vehicle configurations. The subject only has to remember the experience of entering and exiting one vehicle configuration long enough to enter and exit a second configuration and give a response. The Ratings method requires the subject to remember enough different conditions to be able to use the scale consistently over the course of two days of testing. On the other hand, Ratings are easier and faster to collect, allow ingress and egress effects to be examined separately, and, if they can produce good data, are preferred for logistical reasons.

Both methods were used in this study, and the results were compared. However, in order to maximize the information gathered in this study, the two methods were used somewhat differently, so a direct comparison is more difficult. Specifically, Paired Comparisons necessarily reflected a combined ingress/egress comparison, whereas Ratings were gathered separately for the two tasks. In doing so, the assumption was made that the Ratings would prove to be useful, and that some understanding of how a subject combines the experiences of entering and exiting might be gained.

The experiment produced mixed results from a methodological point of view. Several methods of combining Ratings to match Paired Comparisons were tried, but when used for individual subjects' data, none produced a very high correlation. However, when used on aggregated data, all methods produced high correlations. Thus, the Ratings were considered viable for standard aggregated analysis techniques, such as ANOVA, but at an individual level, the relationship between Ratings and Paired Comparisons responses is not well understood. Although it would be useful to understand how subjects make their judgments, the analysis of these data focuses on aggregated data, so it is encouraging that the overall patterns of results for the two methods are so similar.

6.2 Consistency of Differentiation Between Vehicle Configurations

Paired Comparisons is an excellent method to measure the consistency with which subjects differentiate between conditions. The measure of consistency is in the differences between scores for each condition. In this study, subjects were able to distinguish at least some configurations so well that it caused some minor problems for the Paired Comparisons solution. In addition, only 11% of triads across all subjects were intransitive, lending further support for the conclusion that subjects can and do distinguish between configurations consistently, at least at the level of differences presented in this study.

6.3 Effect of Vehicle Factors

Rocker Width

Increasing rocker width made the ingress/egress task significantly more difficult, especially for the short and elderly subjects. It also increased the horizontal forces on the seat and ground.

Seat-to-Ground Distance

Seat-to-ground distance was the single most important influence on rated difficulty of ingress/egress. The highest Hz produced the strongest responses including individual difficulty Ratings of 6 and 7 ("very difficult") and some "unacceptable" Ratings. Seat-to-ground distance did not interact with other vehicle variables, so this study did not point to other design characteristics that could be altered to partially offset the increased difficulty of the high Hz.

Rocker Height

Rocker height with respect to AHP did not significantly influence difficulty Ratings, Paired Comparisons scores, or force-time parameters. Although the range tested did not completely span the range available in production vehicles, it was relatively wide. Because a monotonic relationship between rocker height and ratings would be expected, it would be reasonable to use these results to justify dropping it from future studies.

Door-Hinge Type

This study failed to produce evidence favoring a four-bar hinge, at least for this type of four-door vehicle. The varying weight of the door types may have interfered with the results.

6.4 Relationship Between Force and Difficulty Ratings

Forces exerted by the subject on the ground, wheel, door, and rocker panel were compared to Ratings of ingress/egress difficulty. Although different vehicle configurations produced statistically significantly different force levels on some vehicle components, those differences could not clearly be related to difficulty Ratings. For individual subjects, the most correlated objective measures were time for egress and time for ingress. Averaged across subjects, horizontal force on the seat during ingress and time for ingress and egress were most highly correlated with Ratings. However, all of the correlations were, at best, moderate, with the highest (mean horizontal force on the seat) accounting for about 25% of the variance in Ratings.

6.5 Effect of Subject Characteristics on I/E Difficulty

Subject group had a strong influence on both rated task difficulty and the pattern of the relationships between vehicle variables and rated difficulty. The elderly group generally rated everything as more difficult than did other groups, a result consistent with the assumptions behind previous research that has focused on the elderly. Tall subjects had an easier time maneuvering across longer distances (wider rocker panel, higher seat). The short subjects had difficulty maneuvering across wide rocker panels or getting up to higher seats. The overweight group did not distinguish itself particularly from the midsized control. Because of the difficulty of finding subjects, this group was not restricted to excessively overweight people.

7. CONCLUSIONS

The primary results of this study are listed below:

- Results from Ratings and Paired Comparisons methods do not match as well as had been hoped, but the pattern of results with respect to vehicle factors is similar (e.g., see Figures 7 and 9). Both are considered viable methods for use in ingress/egress testing.

- The egress task was rated as significantly more difficult than the ingress task across conditions. In addition, the effects of rocker width and seat-to-ground distance differ for the two tasks. For rocker width, the difference between egress and ingress was accentuated by more difficult conditions (wider rocker panels). For seat-to-ground distances, the higher the seat-to-ground, the more difficult ingress became, relative to egress. That is, at the lowest seat-to-ground distance, egress was significantly more difficult than ingress. The two tasks were similar at the middle seat-to-ground level, but at the highest seat-to-ground level, ingress was actually more difficult than egress.

- Rocker width and seat-to-ground distance are vehicle factors that have an important influence on perception of the ease of ingress/egress. Ingress/egress difficulty increases monotonically with increasing rocker width. However, the middle seat-to-ground level (575 mm) was rated as easiest, followed by the low level (450 mm) and then the high level (700 mm), which produced the most extreme difficulty ratings, and occasionally "unacceptable" ratings. Rocker height did not affect rated ease of ingress and egress.

- Door type influenced ratings, but the four-bar conditions were generally rated as more difficult than the pivot condition, raising the possibility that subjects' judgments were based on the weight of the door on opening, not the size of the door opening.

- Subject groups differ in their overall rating of ease of ingress and egress, with elderly subjects reporting greater difficulty across all conditions.

- The effect of rocker width and seat-to-ground distance on rated difficulty of ingress and egress varies for different subject groups. As expected, high seat-to-ground distances were not a problem for tall subjects, but caused the greatest difficulty for short and elderly subjects. Increasing rocker width did not influence the judgments of tall male or overweight subjects, but for other groups, increasing rocker width increased the rated task difficulty.

- Ratings were repeatable within and across sessions.

- Subjects focused on vehicle height as an important influence on their rating of acceptability.

- Subjects rarely judged conditions to be unacceptably difficult.

- Parameters of the force-time histories were significantly affected by vehicle variables, but they were not closely related to difficulty ratings.

8. REFERENCES

David, H.A. 1988. *The method of paired comparisons, 2nd ed.* London: Charles Griffin and Co., Ltd.

James, J.G. 1985. *Problems experienced by disabled and elderly people entering and leaving cars*. Report No. TRRL-RR-2. England: Loughborough University of Technology, Institute of Consumer Ergonomics.

Koester, D. and Hamilton, R. (1994) A methodology for evaluating barriers and aids to vehicle ingress/egress. SAE Technical Paper 940388. In *Human Factors: Lighting, Mirrors, and User Needs*, pp. 29-33. Warrendale, PA: Society of Automotive Engineers, Inc.

Loczi, J. 1993. Ergonomic assessment of exiting automobiles. In *Proceedings of the 37th Annual Human Factors and Ergonomic Society Meeting: Designing for Diversity*, Vol. 1, pp. 401-405. Santa Monica, CA.

APPENDICES

APPENDIX A

PAIRED COMPARISONS FORM

FORD INGRESS / EGRESS STUDY
DATA COLLECTION FORM

Subject No.: ______________ Date: __________________ Time: __________________

Session: 1 2 3

Seat Track: __________________
Seatback Angle: __________________
Wheel Tilt: __________________

PAIRED COMPARISONS

PC Input File Name: ______________________________

PC Output File Name: ______________________________

Circle Preference

Trial	Condition	Door Hinge	Rocker Height	Rocker Width	Seat-to-Ground	Comments
1	1					
	2					
2	1					
	2					
3	1					
	2					
4	1					
	2					
5	1					
	2					
6	1					
	2					

APPENDIX B

RATINGS FORMS

INGRESS RATING SCALE

Subject Number____________________ Date____________________

Please circle the number that best rates the ease or difficulty of entering the vehicle. Comment on any factors you feel were the reason for your rating. Check the box provided if you felt that the vehicle setup was unacceptably difficult to enter and would cause you concern if you were driving a vehicle like this daily.

	very easy			average			very difficult
Trial 1..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

	very easy			average			very difficult
Trial 2..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

	very easy			average			very difficult
Trial 3..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

	very easy			average			very difficult
Trial 4..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

	very easy			average			very difficult
Trial 5..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

	very easy			average			very difficult
Trial 6..	1	2	3	4	5	6	7

____
____
____

Unacceptably difficult ☐

Trial 7 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 8 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 9 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 10 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 11 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 12 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 13 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 14 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 15 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 16 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 17 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 18 ....

very easy			average			very difficult
1	2	3	4	5	6	7

Unacceptably difficult ☐

Other Comments: ______________________________

EGRESS RATING SCALE

Subject Number__________________________ Date_________________________________

Please circle the number that best rates the ease or difficulty of exiting the vehicle. Comment on any factors you feel were the reason for your rating. Check the box provided if you felt that the vehicle setup was unacceptably difficult to exit and would cause you concern if you were driving a vehicle like this daily.

Trial 1..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 2..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 3..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 4..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 5..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 6..

very easy			average			very difficult
1	2	3	4	5	6	7

____

____

____

Unacceptably difficult ☐

Trial 7	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 8	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 9	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 10	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 11	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 12	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 13	very easy			average			very difficult
	1	2	3	4	5	6	7

Unacceptably difficult ☐

Trial 14	very easy 1	2	3	average 4	5	6	very difficult 7

Unacceptably difficult ☐

Trial 15	very easy 1	2	3	average 4	5	6	very difficult 7

Unacceptably difficult ☐

Trial 16	very easy 1	2	3	average 4	5	6	very difficult 7

Unacceptably difficult ☐

Trial 17	very easy 1	2	3	average 4	5	6	very difficult 7

Unacceptably difficult ☐

Trial 18	very easy 1	2	3	average 4	5	6	very difficult 7

Unacceptably difficult ☐

Other Comments: ______________________________

APPENDIX C

SUBJECT FORMS

The University of Michigan Transportation Research Institute
Research Involving Human Subjects
INFORMED CONSENT FOR EXPERIMENTAL PROCEDURE

AUTOMOBILE INGRESS / EGRESS STUDY

I understand that the purpose of this study is to investigate the factors that affect the ease or difficulty of getting in and out of a vehicle. I will be asked to compare and rate my experience of entering and exiting various vehicle design setups. I will be asked to participate in two future test sessions lasting approximately 1-1/2 to 2 hours each.

I understand that my participation in this study is voluntary and is conditional to review of my responses to a health questionnaire and my physical qualifications with regard to experimental design criteria. I understand that I will be paid for my participation at a rate of $10/hr., and that I may discontinue my involvement at any time without prejudice or change in my rate of pay.

The Transportation Research Institute is a research organization and, as such, my records and personal information may be reviewed by research staff. I acknowledge however, that all data and results, including photographs and video tapes, will remain confidential and will be used in scientific publications and presentation only in a manner not identifying me.

In the unlikely event of physical injury resulting from research procedures, the University will provide first-aid medical treatment. Additional medical treatment will be provided in accordance with the determination by the University of its responsibility to provide such treatment. However, the University does not provide compensation to a person who is injured while participating as a subject in research.

If significant new knowledge is obtained during the course of this research which may relate to my willingness to continue participation, I will be informed of this knowledge. The person(s) listed below may be contacted for more information about any aspect of this study. Any questions or concerns about my rights as a research subject, may be directed to the Office of Patient-Staff Relations, L5003 Women's Hospital, University of Michigan Medical Center, Ann Arbor, Michigan 48109-0275, Telephone 763-5456.

One copy of this document will be kept together with research records on this study. A second copy has been given to me to keep.

I agree to the conditions set forth above and have had an opportunity to discuss my concerns regarding participation in the proposed study. I hereby consent to participate in the study.

SUBJECT NAME (please print) ______________________________

Signature: ____

WITNESS Signature: ______________________________________ Date: _____________

Investigator(s): Lawrence W. Schneider, Ph.D. 936-1103 (work), 996-3861 (home)

Subject No.____________
Gender______________

SUBJECT INFORMATION FORM

SUBJECT NAME:________________________ HT:____________

PHONE NUMBER WT:____________

HOME:____________________ AGE:____________

WORK:____________________

YEARS OF DRIVING:__________________

Please list the vehicles you currently drive regularly, in order of frequency. (Include YEAR AND MODEL)	Manual Seats		Transmission	
1. ________________________	Y	N	Auto	Manual
2. ________________________	Y	N	Auto	Manual
3. ________________________	Y	N	Auto	Manual

Approximate miles per year driven:____________________________________

The University of Michigan Transportation Research Institute

HEALTH QUESTIONNAIRE

(please print)

SUBJECT NO: ____________
DATE: ____________

NAME: ____ PHONE (S): ____________________
Last First Middle
____

ADDRESS: ____
Street City State Zip

SOCIAL SECURITY NO.: ______________________ BIRTHDATE: ____________ AGE: _______

HEIGHT: ____________ WEIGHT: ____________

DIRECTIONS: Answer all questions. If you are uncertain as to how to best answer a question please circle *Yes* or *No* and explain further either at space provided after question or at the end of the questionnaire with the letter and # marked.

1. Do you have a valid and current driver's license? *Yes* *No*
   a. Approximately how many miles do you drive a year? ______________________
2. Does severe rheumatism (or arthritis) interfere with your work? *Yes* *No*
3. Are you under a doctor's care? *Yes* *No*
   a. If yes, give name of doctor: ______________________
4. Are you currently taking any medications? *Yes* *No*
   a. If yes, give name of medication: ______________________
5. Do you need glasses for reading or other close work? *Yes* *No*
6. Do you need glasses for seeing things at a distance? *Yes* *No*
7. Were you ever in an automobile accident where you might have suffered "whiplash" or neck injury? *Yes* *No*
8. Has a doctor ever said your blood pressure was too high or too low? *Yes* *No*
9. Do you have pains in the back or neck that make it hard for you to keep up with your daily activities? *Yes* *No*
10. Are you troubled by a serious bodily disability or deformity? *Yes* *No*
    a. If yes, please explain: ______________________
11. Were you ever knocked unconscious? *Yes* *No*
    a. If yes, please explain: ______________________
12. Have you ever had a serious injury? *Yes* *No*
    a. If yes, please explain: ______________________

Additional comments: (Please include date, symptoms, frequency of occurrence, and any other relevant data)

____

* NOTE: This questionnaire modified from the Cornell Medical Index for the R.L.W.U. multiphase testing, June 1951.

Subject No.____________________

Subject Anthropometry

1. Stature with shoes:_________________________ mm
2. Stature without shoes:_________________________ mm
3. Age:______________________________________ yrs
4. Weight without shoes:_________________________ lbs
5. Standing shoulder height:_______________________ mm
6. Shoulder-elbow length:________________________ mm
7. Elbow-hand length:___________________________ mm
8. Erect sitting height:___________________________ mm
9. Erect eye height (sitting):_______________________ mm
10. Knee height (sitting):_________________________ mm
11. Popliteal height (sitting):_______________________ mm
12. Buttock-popliteal length (sitting):_________________ mm
13. Buttock-knee length (sitting):____________________ mm
14. Shoulder breadth:____________________________ mm
15. Hip breadth (sitting):___________________________ mm
16. Shoe length:_________________________________ mm
17. Shoe heel height:_____________________________ mm

APPENDIX D

FINAL INGRESS/EGRESS QUESTIONNAIRE AND RESPONSE SUMMARY

INGRESS FINAL RATING

Subject Number____________________ Date____________________

In thinking about the acceptability of a vehicle setup when ENTERING a vehicle, how important were the following factors? Please circle the number.

	not at all			average			very
1. Bumping leg or foot on rocker panel...........	1	2	3	4	5	6	7
2. Having to bend over to clear roof rail.......	1	2	3	4	5	6	7
3. Having to reposition yourself after sitting on the seat cushion..................................	1	2	3	4	5	6	7
4. Bumping steering wheel with legs..........	1	2	3	4	5	6	7
5. Bumping side of instrument panel...........	1	2	3	4	5	6	7
6. Needing to adjust the seat track to enter the vehicle..	1	2	3	4	5	6	7
7. Needing to adjust the steering wheel tilt to enter the vehicle....................................	1	2	3	4	5	6	7
8. Vehicle too low to the ground..................	1	2	3	4	5	6	7
9. Vehicle too high from the ground..............	1	2	3	4	5	6	7
10. Having to rotate your body to squeeze in the door...	1	2	3	4	5	6	7
11. Being able to lower yourself gently into the seat..	1	2	3	4	5	6	7
12. Placing too much stress on knees when lowering self into seat....................	1	2	3	4	5	6	7
13. Having difficulty opening and/or closing the door...	1	2	3	4	5	6	7

Please use the following space to make any additional comments about what you think makes getting into an automobile easy or difficult.____________________

____

____

EGRESS FINAL RATING

Subject Number________________________ Date______________________________

In thinking about the acceptability of a vehicle setup when EXITING a vehicle, how important were the following factors? Please circle the number.

Factor	1 (not at all)	2	3	4 (average)	5	6	7 (very)
1. Bumping leg or foot on rocker panel..........	1	2	3	4	5	6	7
2. Having to bend over to clear roof rail.........	1	2	3	4	5	6	7
3. Hitting leg or foot on door........................	1	2	3	4	5	6	7
4. Hitting upper body on door/window..........	1	2	3	4	5	6	7
5. Bumping steering wheel with legs...........	1	2	3	4	5	6	7
6. Bumping side of instrument panel..........	1	2	3	4	5	6	7
7. Needing to adjust the seat track to exit the vehicle..	1	2	3	4	5	6	7
8. Needing to adjust the steering wheel tilt to exit the vehicle....................................	1	2	3	4	5	6	7
9. Vehicle too low to ground.....................	1	2	3	4	5	6	7
10. Vehicle too high from ground.................	1	2	3	4	5	6	7
11. Having to rotate your body to squeeze out the door..	1	2	3	4	5	6	7
12. Placing too much stress on knees when lifting self from seat..............................	1	2	3	4	5	6	7
13. Having difficulty opening and/or closing the door..	1	2	3	4	5	6	7

Please use the following space to make any additional comments about what you think makes getting out of an automobile easy or difficult.____

____

____

Table D.1
Mean Responses to Final Questionnaire Items by Subject Group

Question	Subject Group					Overall Mean
	Short	*Mid-sized*	*Tall*	*Elderly*	*Overweight*	
Bump rocker panel on ingress[1]	4.0	5.2	5.0	5.0	4.7	4.8
Bump rocker panel on egress[1]	6.2	5.7	4.8	4.8	4.5	5.2
Bend for roof rail on ingress[2]	4.7	2.5	3.8	6.0	3.8	4.2
Bend for roof rail on egress[2]	3.2	2.8	3.5	5.2	3.7	3.7
Bump wheel[3]	2.9	4.3	4.8	6.5	4.5	4.6
Bump instrument panel	2.8	3.6	3.1	5.6	3.8	3.8
Adjust seat position on ingress[2]	2.2	3.2	2.8	6.2	4.0	3.7
Adjust seat position on egress[2]	1.8	3.2	3.2	5.0	2.5	3.1
Adjust tilt wheel	2.2	3.4	3.2	4.7	3.6	3.4
Seat-to-ground distance too low	5.3	4.8	5.9	6.3	5.8	5.6
Seat-to-ground distance too high	6.7	5.8	5.1	6.7	5.3	5.9
Stress on knees	3.9	3.5	4.7	5.9	4.8	4.6
Difficulty with door	4.5	4.6	4.0	4.9	2.8	4.2
Rotate body	5.3	5.5	4.7	5.6	5.5	5.3
Reposition body on ingress	5.3	4.5	3.7	5.0	4.8	4.7
Lower self gently on ingress	5.8	4.5	4.8	5.7	4.0	5.0
Hit leg on door on egress	4.0	4.2	5.3	5.7	4.7	4.8
Hit upper body on door on egress	3.0	4.7	4.8	6.2	4.5	4.6

[1]Task x subject group interaction significant.
[2]Task effect significant.
[3]Subject group effect significant.

APPENDIX E

PAIRED-COMPARISONS SCORING PROCEDURE

The Bradley-Terry method was used to assign scores to the Paired -omparisons conditions for each subject (David 1988). Thurstonian scaling is probably more widely used, but Thurstonian scaling requires that all possible pairs be presented to the subject several times in order to generate scores. In this case, only a subset of the pairs was presented, and each pair was presented only once.

The Bradley-Terry method is analogous to rankings of sports teams in which the quality of the "opponent" is considered in addition to the number of times a condition was preferred over other conditions. The formula (Equation E.1) must be solved iteratively. In order to ensure a unique solution, the scores (p_i) are constrained to sum to 1.

$$p_i = \frac{a_i}{\sum_j n_{ij}\left(p_i + p_j\right)^{-1}} \tag{E.1}$$

where,

p_i=score assigned to condition *i*,
a_i=total number of times condition *i* is preferred over any other condition,
n_{ij}=number of trials in which condition *i* and condition *j* are compared.

As with Thurstonian scaling, the solution depends on subjects being at least slightly inconsistent in their judgments. The equation will converge as long as there is no condition that is judged either easier than all others or harder than all others to which it is compared. For example, if condition A is judged easier than all other conditions, it is compared to, it should be assigned a lower score than any of the others. However, there is no way to judge *how much* easier it is, because no limit has been observed.

In designing this study, there was concern that subjects could not consistently distinguish between conditions at all. Thus, a wide range of conditions was used, and an extreme condition (C30: 500/700/100) was included. Perhaps ironically, subjects' preferences were consistent enough to make most of the scaling solutions unstable. That is, most subjects judged at least one condition easier than, or harder than, all conditions to which it was compared. Thus, a stable solution could not be reached.

To handle this problem, a standard set of starting conditions and a consistent stopping rule were developed. The starting value of p_i for each condition was set to a_i divided by 18 (the total number of responses. The solution was allowed to run for 200 iterations, by which point, changes from iteration to iteration were relatively small. Every solution was inspected carefully to check whether the numbers and their relative distances made intuitive sense. For example, Table E.1 shows the raw results alongside the scores. Note that, although Conditions 2 and 3 were both preferred to all four conditions they were compared to, Condition 3 is assigned a score of .75 to a score of .20 for Condition 2. Turning to the raw data, Condition 2 was preferred to Conditions 1, 5, 6, and 8, which were preferred 2, 0, 1, and 2 times, respectively. In contrast, Condition 3 was preferred to Conditions 1, 4, 6, and 7, which were preferred 2, 2, 1, and 3 times, respectively. Thus, Condition 3 was preferred to more "worthy" opponents, and the solution makes intuitive sense.

Table E.1
Raw Data from Paired Comparisons and Scale Scores for One Subject

Condition A	Condition B	Subject Preference	Condition	a_i	p_i
1	3	3	1	2	0.0018
1	5	1	2	4	0.2039
2	1	2	3	4	0.7547
2	6	2	4	2	0.0001
3	4	3	5	0	0.0000
3	7	3	6	1	3.82E-06
4	6	4	7	3	0.0391
4	8	8	8	2	0.0024
5	2	2	9	0	0.0000
5	4	4			
6	3	3			
6	9	6			
7	5	7			
7	8	7			
8	2	2			
8	9	8			
9	1	1			
9	7	7			

In addition to checking each individual solution, the results of the ANOVA on the log-transformed PC scores were checked against the results of an analogous nonparametric analysis technique (Friedman's one-way analysis of variance). Furthermore, the results were compared to the results from the ratings portion of the experiment. Although the PC scores were intended to validate the Ratings, their mutual agreement is strong evidence of the validity of both. Given that the potential problem with the PC method is completely independent of potential problems with ratings, it would be unlikely, indeed, for the two results to agree so closely without reflecting some underlying consistency in the data.

In all, the results of the Paired-Comparisons portion of the study are judged to be valid. If the method is to be used in future studies, either fewer conditions should be compared or more trials should be run to prevent the instability seen in these solutions. Clearly, subjects' ability to distinguish among these different configurations should not be underestimated.

APPENDIX F

HISTOGRAMS OF FORCE AND TIME PARAMETERS

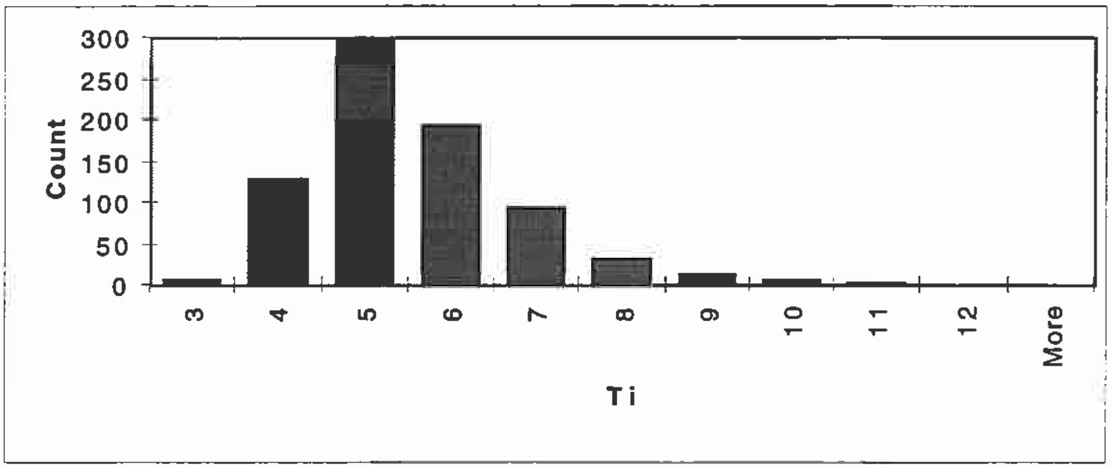

Figure F.1. Histogram of time for ingress.

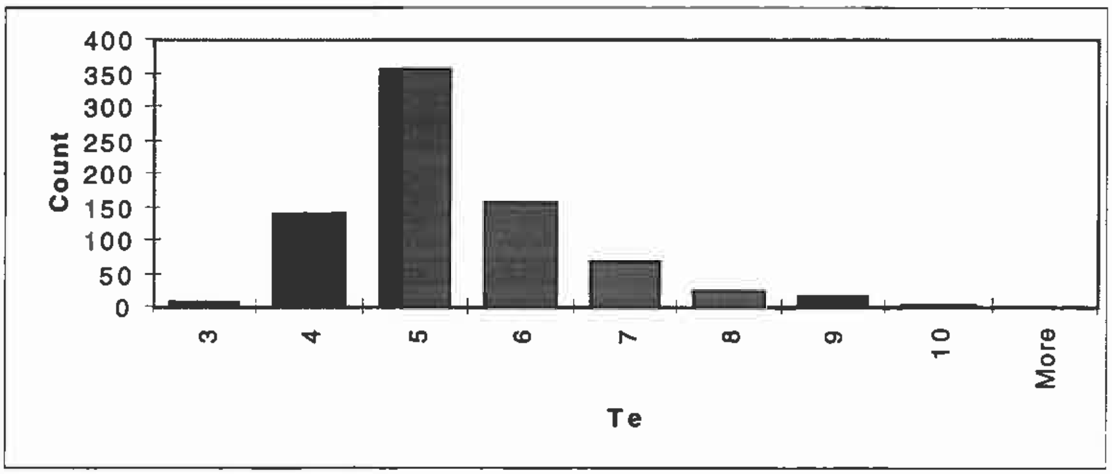

Figure F.2. Histogram of time for egress.

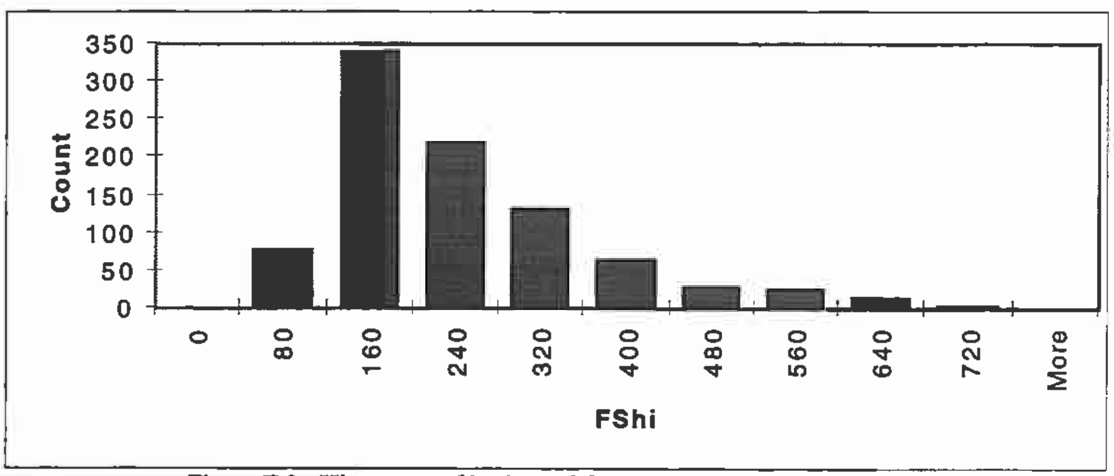

Figure F.3. Histogram of horizontal force on the seat during ingress.

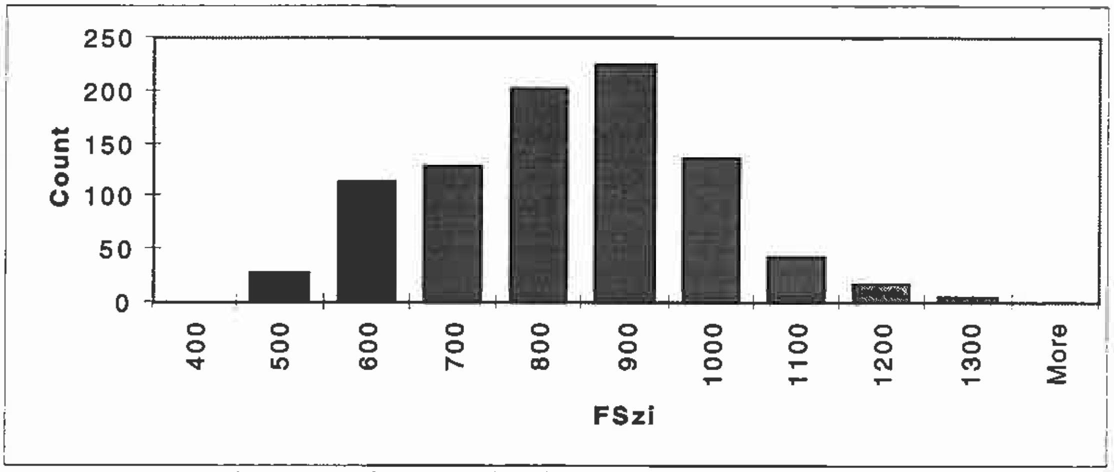

Figure F.4. Histogram of vertical force on the seat during ingress.

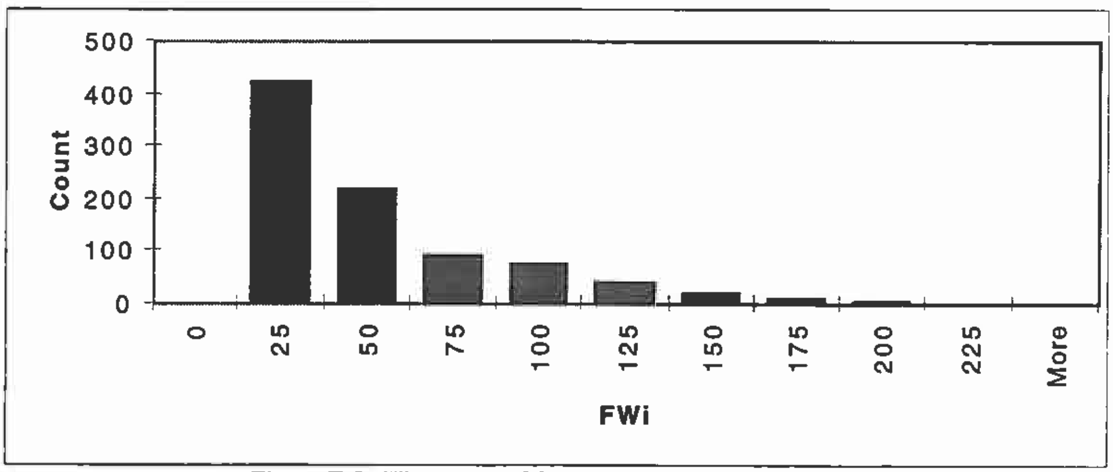

Figure F.5. Histogram of force on the wheel during ingress.

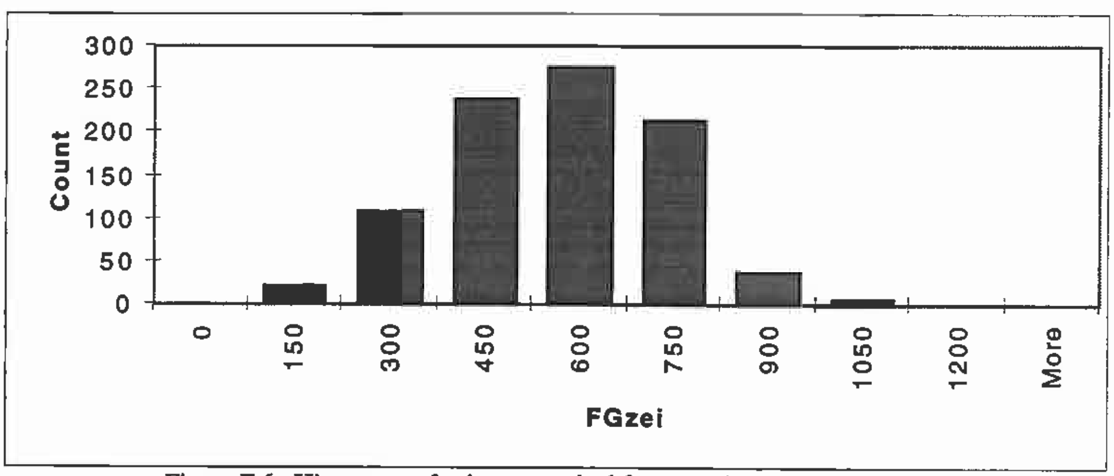

Figure F.6. Histogram of primary vertical force on the ground during egress.

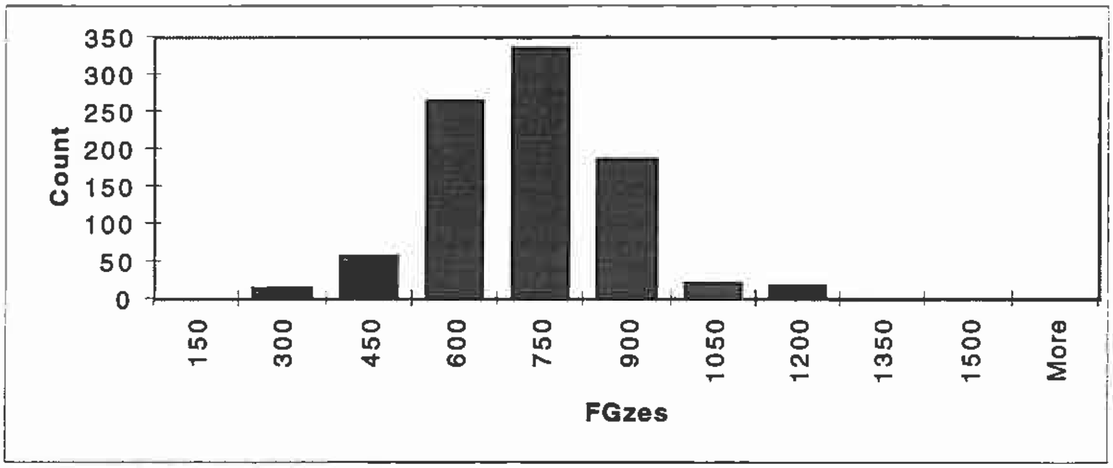

Figure F.7. Histogram of secondary vertical force on the ground during egress.

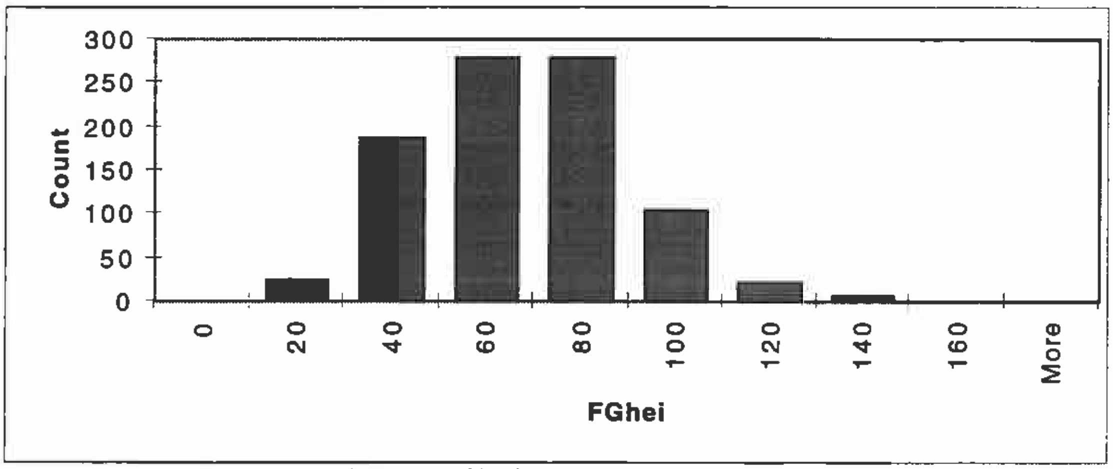

Figure F.8. Histogram of horizontal force on the ground during egress.

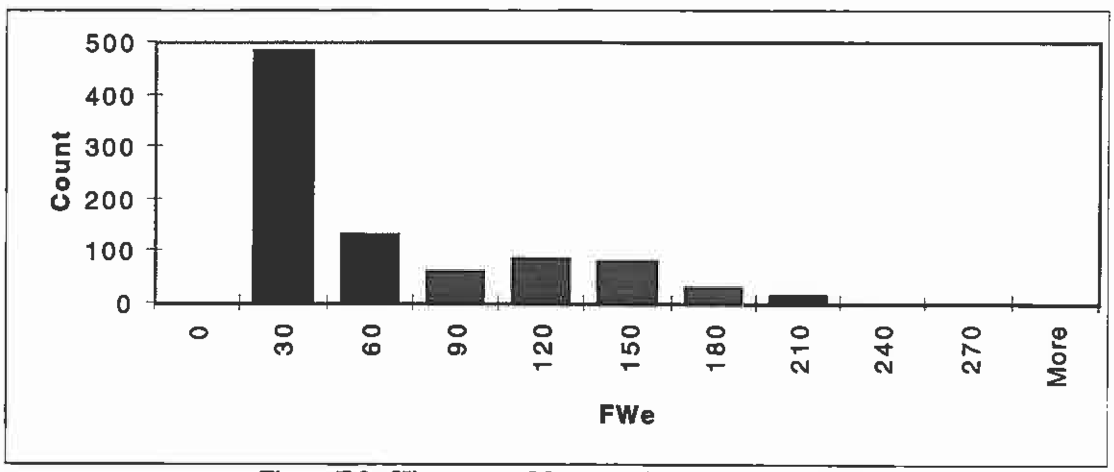

Figure F.9. Histogram of force on the wheel during egress.

APPENDIX G

MEAN VALUES OF FORCE AND TIME PARAMETERS

Table G.1
Subject-Group Means on Various Force Parameters

Force Parameters	Subject Group					Overall Mean
	Short	Mid-Sized	Tall	Elderly	Overweight	
T_i (s)	5.0	4.9	4.5	6.3	4.8	5.1
T_e (s)	4.8	4.6	4.4	5.6	4.4	4.8
FS_{hi} (N)	128.4	214.9	240.9	174.6	250.5	201.9
FS_{zi} (N)	696.3	786.1	855.1	675.9	902.9	783.3
FW_i (N)	29.7	48.3	42.9	39.0	32.1	38.4
FG_{zei} (N)	405.9	529.1	492.8	485.0	536.5	489.9
FG_{zes} (N)	509.8	658.7	685.7	659.1	738.7	650.4
FG_{he} (N)	48.4	60.6	61.2	53.6	64.7	57.7
FW_e (N)	30.8	72.5	54.8	48.2	50.0	51.3

Significant effects are shaded.

Table G.2
Means of Force Parameters for Different Door Types

Force Parameters	Door Type				Overall Mean
	Pivot	4-bar (a)	4-bar (b)	No Door	
T_i (s)	5.0	5.1	5.3	n/a	5.1
T_e (s)	4.6	5.1	5.3	n/a	5.0
FS_{hi} (N)	202.6	216.0	208.6	200.3	206.9
FS_{zi} (N)	798.3	796.7	782.6	762.2	785.0
FW_i (N)	44.7	47.1	40.4	34.9	41.8
FG_{zei} (N)	484.2	477.5	475.3	520.1	489.3
FG_{zes} (N)	652.2	652.5	653.3	661.0	654.8
FG_{he} (N)	60.3	56.1	59.9	56.4	58.2
FW_e (N)	57.5	60.4	55.7	30.0	50.9

Significant effects are shaded.

Table G.3
Means of Force Parameters for Different Rocker Widths

Force Parameters	Rocker Width			Overall Mean
	400 mm	450 mm	500 mm	
T_i (s)	5.1	5.0	5.2	5.1
T_e (s)	4.7	4.8	4.9	4.8
FS_{hi} (N)	199.6	193.8	212.2	201.9
FS_{zi} (N)	784.7	785.0	780.1	783.3
FW_i (N)	38.5	37.0	39.7	38.4
FG_{zei} (N)	505.6	471.1	492.9	489.9
FG_{zes} (N)	657.5	642.3	651.4	650.4
FG_{he} (N)	54.6	57.8	60.7	57.7
FW_e (N)	49.1	51.2	53.4	51.2

Significant effects are shaded.

Table G.4
Means of Various Force Parameters for Seat-to-Ground Levels

Force Parameters	Seat-to-Ground Distance			Overall Mean
	450 mm	575 mm	700 mm	
T_i (s)	5.1	4.8	5.4	5.1
T_e (s)	4.8	4.6	4.9	4.8
FS_{hi} (N)	193.7	195.4	216.5	201.9
FS_{zi} (N)	810.8	784.2	754.7	783.2
FW_i (N)	46.1	36.0	33.1	38.4
FG_{zei} (N)	459.8	493.4	516.4	489.9
FG_{zes} (N)	627.4	654.5	669.2	650.4
FG_{he} (N)	59.9	56.5	56.7	57.7
FW_e (N)	58.3	49.3	46.1	51.2

Significant effects are shaded.

APPENDIX H

PHOTOS OF INGRESS/EGRESS TEST FACILITY

Figure H.1 Overview of ingress/egress test buck with **low** seat-to-ground distance.

Figure H.2 Overview of ingress/egress test buck with **high** seat-to-ground distance.

Figure H.1 Overview of ingress/egress test buck with **low** seat-to-ground distance.

Figure H.2 Overview of ingress/egress test buck with **high** seat-to-ground distance.

Figure H.3 Subject getting in ingress/egress test buck.

Figure H.4 Door of ingress/egress test buck opened using **production pivot** hinge position.

Figure H.5 Door of ingress/egress test buck opened using **4-bar (a)** linkage condition.

Figure H.6 Door of ingress/egress test buck opened using **4-bar (b)** linkage condition.

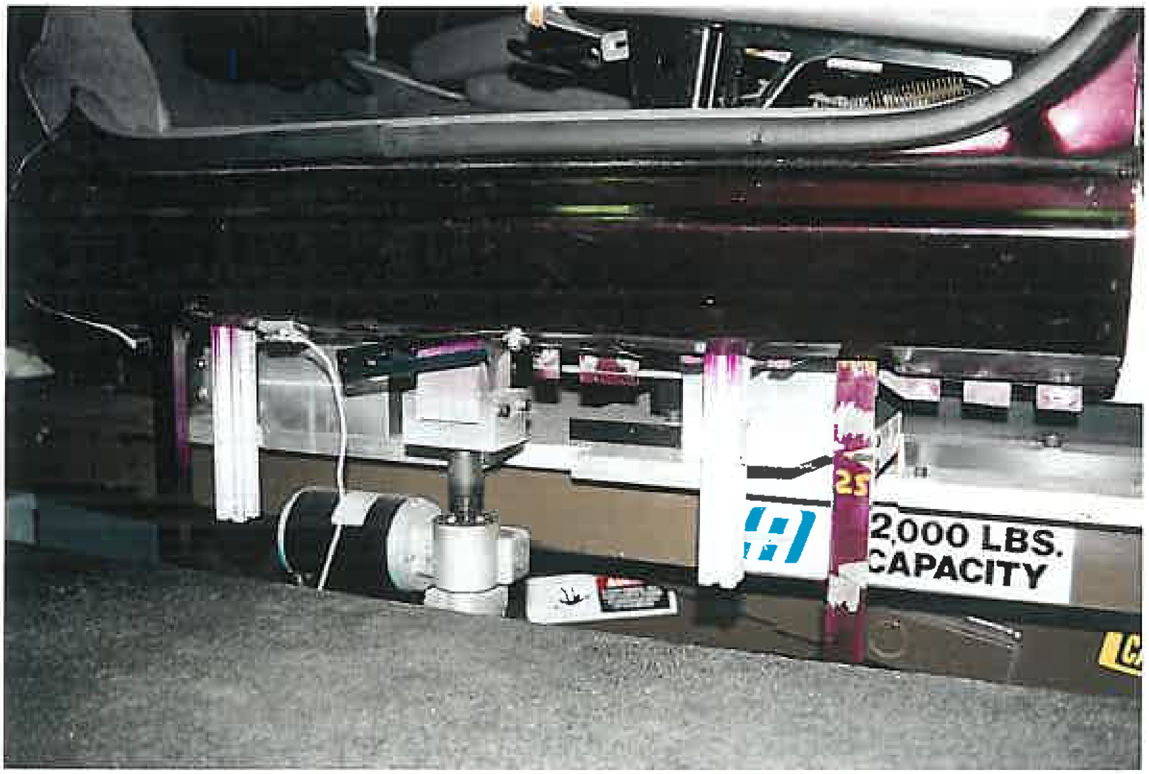

Figure H.7 Rocker height adjustment mechanism with rocker in low (25 mm above AHP) position.

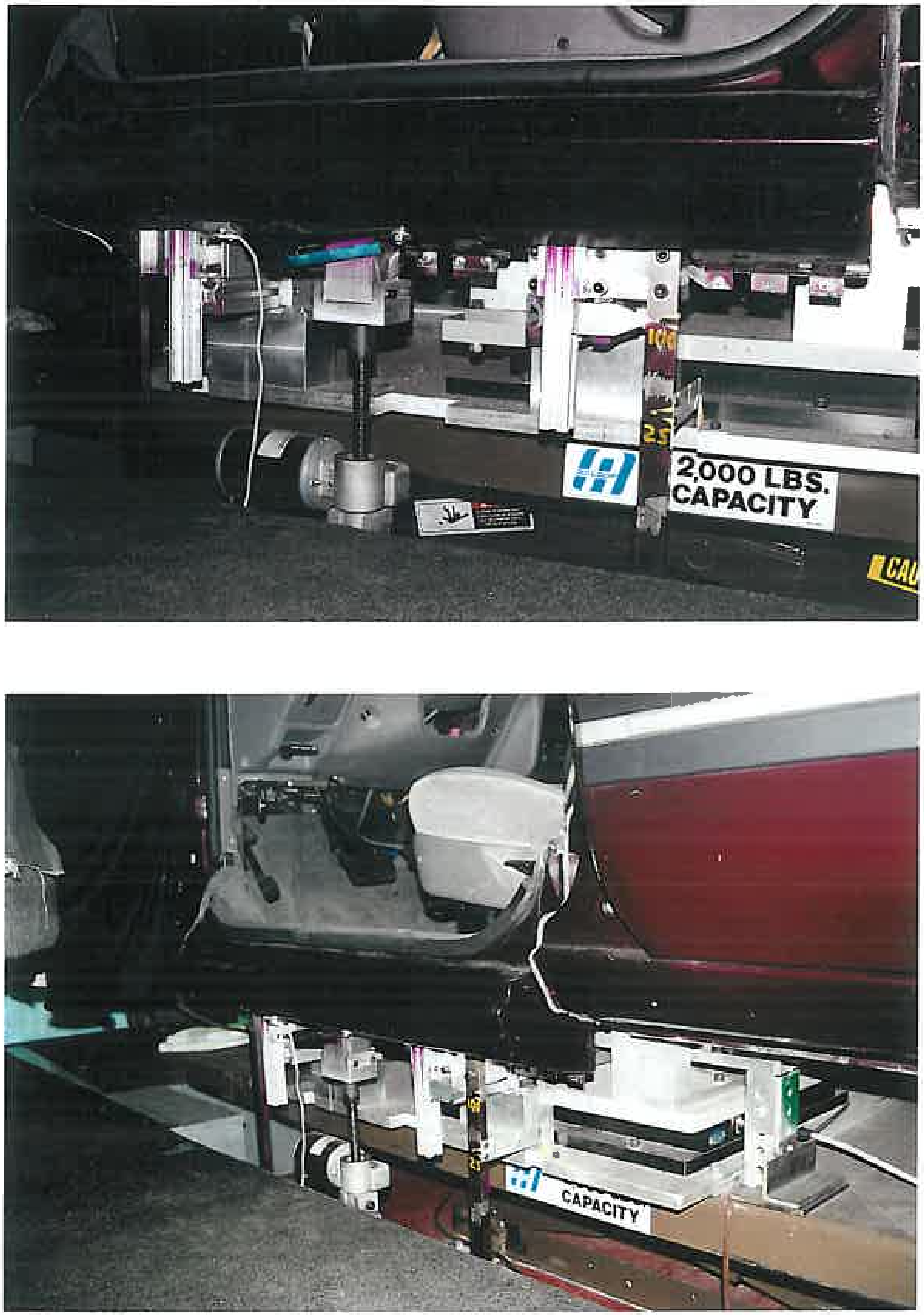

Figure H.8 Rocker height adjustment mechanism with rocker in **high** (100 above AHP) position.