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An analysis of human comfort when entering and exiting the rear seat of an automobile

J. Giacomin* and S. Quattrocolo

DVS—Human Factors, Centro Ricerche Fiat, Strada Torino 50, 10043 Orbassano (TO), Italy

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This paper describes a study of human motion and human comfort when entering and exiting the rear seat of an automobile. A simulator was used to test several possible door frame configurations, and various positions of the front and rear seats. Thirty-six human subjects were asked to enter and exit the simulator five times for each configuration and to answer a subjective questionnaire. The motion performed by each test subject was recorded by means of a VHS recorder and an ELITE motion measurement system. A statistical analysis was performed on the data from the questionnaires and comfort rankings were produced for the various configurations. The most influential design parameters were identified and iso-comfort surfaces were defined and fitted which provided a simple means of quantifying the effect of one of the main parameters. © 1997 Elsevier Science Ltd

Introduction

Vehicular researchers have performed a number of studies to better understand the problems associated with entry and exit. Case studies have been performed for a number of vehicles including aircraft and tractors (Bottoms *et al*, 1979; Petzäll, 1995; Roebuck and Levedahl, 1961). Several studies quantified the ease of movement by measuring the total time required to perform the ingress or egress manoeuvre. Useful design criteria were produced in the form of graphs in which the total time required is plotted against the door frame parameters. Other studies such as the one by Loczi (1993) measured the body angles associated with the various phases of ingress and egress. These body angles were used to calculate spinal loadings and the best configurations were assumed to be those which produced the lowest loadings.

Research in the medical and bioengineering fields (Adrian and Cooper, 1995; Cooke and Diggles, 1984; Davis *et al*, 1991; Darling *et al*, 1988; Pedotti *et al*, 1989; Giannini *et al*, 1994; Rose and Gamble, 1994; Sparrow, 1983) has defined a number of useful measurement methods and has provided many insights into the workings of the human nervous system and the motion strategies adopted. These studies have been, however, mostly concerned with pathological human gait, rehabilitation and artificial walking, and have thus not addressed problems such as vehicular ingress and egress directly.

The objectives of this study were to evaluate human comfort associated with automobile ingress and automobile egress, and to quantify the effects of varying some of the fundamental design parameters of the door frame and seats. Subjective questionnaires and a motion measurement system were used to perform laboratory tests. Analysis was performed on the subjective responses and measured motions. General trends are discussed and the most critical elements of the door frame identified. A simple method for using the motion data of the head as a metric for measuring the suitability of the roof rail is also presented.

Apparatus

A simulator was used for this study which reproduced the geometry of an automobile front seat, rear seat, door and door frame. The front seat was adjustable in terms of height and for-aft position while the rear seat was adjustable in terms of height and backrest inclination. The door frame consisted of a series of concentric metal bars connected together by means of six universal joints. The node points (joints) could be placed to within 0.5 cm of the geometry of current production automobiles, any remaining differences being recuperated by means of rubber trim. The simulator door was taken from an Alfa Romeo 155 (a European market segment D automobile) and modified. This door was cut in a number of points so as to reduce line of site problems with the emitter/camera units used for measuring the motion of the test

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*Present address: Department of Mechanical Engineering, The University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

Figure 1 The ingress/egress simulator

subjects. The outer rim and the most intrusive elements of the door (such as the corners) were, however, left untouched. The door was adjustable in terms of height above ground, distance from the seats and aperture angle. The complete simulator is shown in *Figure 1*.

The current study required a system for measuring the motion performed by the test subjects (Sternini and Cerrone, 1994). These systems (Adrian and Cooper, 1995; Ferrigno and Pedotti, 1985; Giannini *et al*, 1994; Rose and Gamble, 1994) fall into two broad categories, those based on active sensors and those which use, instead, passive sensors. Since automobile door frames are small apertures which require complex three-dimensional entry and exiting motions, a passive system was chosen so as to avoid interfering with the test subjects. The system used was the ELITE system (Ferrigno and Pedotti, 1985) which consists of a series of measurement stations in the form of light emitters and CCD camera units. Passive reflectors placed on the human body serve to identify the points being monitored. For the calibration volume (roughly 2 cubic metres) used during the current study, measurement accuracy was within 2 millimetres of true. *Figure 2* presents a photograph of two of the emitter/camera units and the system hardware.

Subjective questionnaire

A subjective questionnaire was required to evaluate the comfort associated with entering and exiting the simulator. While studies of vehicle ingress/egress were identified in the literature (Bottoms *et al*, 1979; Loczi, 1993; Petzäll, 1995; Roebuck and Levedahl, 1961), no questionnaires were found. One was therefore designed which consisted of three groups of questions. The first section was filled out by the test subject before beginning the trials. This section asked the subject to state their age, sex, height, weight, any sports played, and whether or not they had any physical or medical problems.

The second group of questions was presented to the subject after testing each simulator configuration. These included an overall rating of the ingress comfort and an overall rating for the egress comfort. The

Figure 2 The motion measurement system

subject was also asked to give a comfort rating for four body areas: the head/neck region, the arms, the back and the legs. All evaluations were made using a five point scale, with a 'very comfortable' rating being assigned a numerical value of 1 and a 'very uncomfortable' rating being assigned the value 5. Each subject was further asked to identify which part of the simulator most hindered ingress/egress. The final section of the questionnaire was compiled after completing all tests, it asked whether any part of the simulator had been bumped and which body parts were moved with the least comfortable motions. The final question was whether the simulator was considered to be realistic when compared to real automobiles.

Door frame and seat parameters investigated

The simulator configurations that were tested were created by changing one parameter of interest at a time starting from a base configuration. The base configuration chosen for this study was the rear cabin design of the Alfa Romeo 155 automobile, the measurements of which are given in *Table 1*. All other configurations were created by making steps of 2 or 4 cm in the individual parameters starting from the base configuration.

Time and data storage constraints limited the total number of tests that could be performed. Attention was focused on four design parameters which were thought important based on previous experience. These parameters were the height of the roof rail, the sill height, the rear seat height, and the distance between the front and rear seats (see *Figure 3*).

Four configurations were defined by changing the roof rail height, two by changing the sill height, two configurations were defined by changing the rear seat height and a final configuration was defined by changing the distance between the front and rear seats. The total number of configurations tested (counting the base configuration and all variations) was therefore ten, which are listed *Table 2*.

Test subjects and test protocol

Thirty-six subjects ranging from 18 to 60 years of age were tested. The average age was 31, with a standard deviation of 12. The subjects were chosen so as to obtain a reasonably uniform distribution of statures from a 5th percentile Italian female to a 95th percentile Italian male. From Masali *et al* (1992) and Masali and Fubini (1992) this range was taken to be from 150 to 190 cm.

The first item of the test protocol that was established was where to position the markers on the subjects. These locations were established by trial and error, the final choice being shown in *Figure 4*. These locations provided a model of the human body that was sufficient for the purposes of the current study, and at the same time provided reasonable line of sight during ingress/egress. *Figure 5*a presents a photograph of one phase of an entry test, while *Figure 5*b presents three frames of the motion data acquired.

A second item that needed to be established was the measurement error. The greatest measurement error encountered was introduced by skin motion artefacts due to the relative motion that occurs between the bone structures and markers on the skin. Differences of up to 1.5 cm have been demonstrated in the literature for the most problematic points such as the greater trochanter (Cappozzo *et al*, 1993) and preliminary runs confirmed these values.

A fundamental aspect of the test protocol was the

Table 1 Fundamental measurements of the base configuration

Parameter	Value
Roof rail height from ground	132.4 cm
Sill height from ground	36.0 cm
Front and rear backrest angles with respect to the vertical	23 degrees
Height of front seat H-point from ground	54.4 cm
Height of rear seat H-point from ground	56.0 cm
Height of rear seat H-point from the car floor	33.7 cm
Distance between front and rear seat H-points	74.5 cm

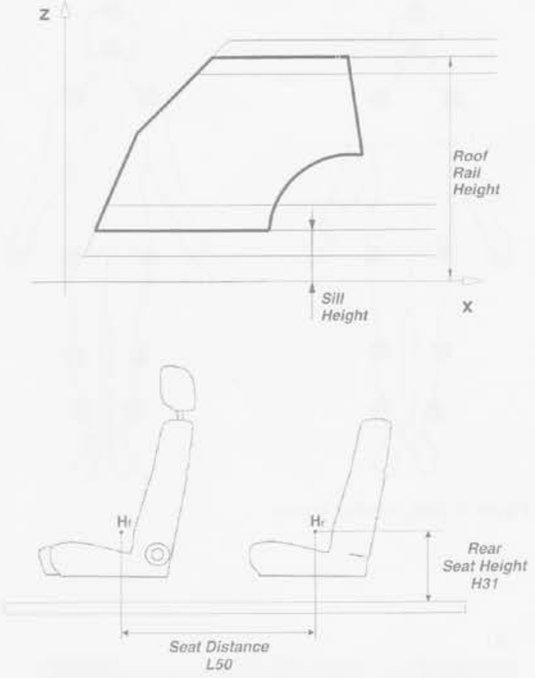

Figure 3 Door frame and seat parameters studied

Table 2 Simulator configurations tested

Parameter	Configurations tested
Roof rail height	Base configuration +4 cm Base configuration +2 cm Base configuration Base configuration −2 cm Base configuration −4 cm
Sill height	Base configuration +2 cm Base configuration Base configuration −2 cm
Rear seat height (H31)	Base configuration +2 cm Base configuration Base configuration −2 cm
Distance between the H-points of the front and rear seats (L50)	Base configuration +4 cm Base configuration

work flow with the subjects. Each subject was asked to fill out the first section of the questionnaire, then was escorted to the changing room where a gymnastic body suit was put on and the body markers applied. At this point each subject was asked to enter and exit the simulator to become acquainted with the test. Five ingress/egress motions with the first simulator configuration were then performed. Each subject chose the starting point, but was suggested to remain just slightly behind and outwards of the door opening. The door itself was always open at a 70 degree angle with respect to the longitudinal axis of the simulator. The subjects were instructed to obtain a final seated posture in which they were centred over the left half of the rear seat, in a comfortable position, and with their hands placed on top of the backrest of the front seat. Each of the five ingress/egress motions was recorded with a VHS recorder and with the ELITE motion tracking system. The ELITE system was used in a four emitter/camera unit layout with 100 Hz sampling rate. After completing the five motions, the subjects were asked to fill out the portion of the questionnaire which asked the comfort ratings for each configuration. The order of presentation of the simulator configurations was randomised independently for each test subject so as to break the structure of learning or fatigue effects. Average ingress time from all tests of all subjects was found to be 3.01 s ($\sigma = 0.27$) while the average egress time was 3.2 s ($\sigma = 0.27$).

A final aspect of the test protocol was the definition of the reference axis for the motion data. The standard axes were used which define automobile interiors, the origin of which passed through the H point (Society of Automotive Engineers, 1989) of the rear seat. From this zero, all co-ordinates are given in centimetres with the positive directions being forwards towards the front of the car in the longitudinal direction, from the driver's side of the car towards the passenger's side in the lateral direction and upwards towards the roof in the vertical direction.

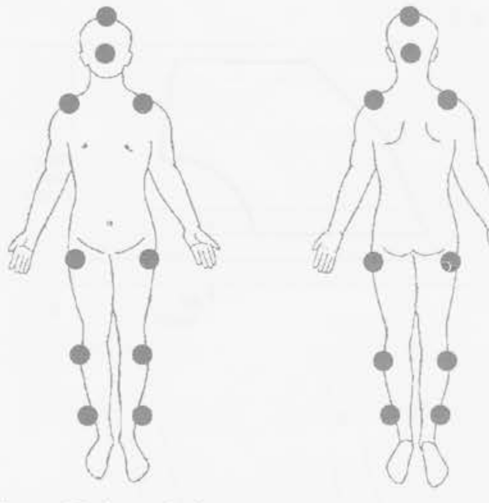

Figure 4 Body marker layout

Figure 5 Example of the ingress/egress tests. (a) Test subject. (b) Measured data

Results

Subjective ratings

Figures 6–11 present the overall rating of ingress comfort and the overall rating of egress comfort in terms of the average value and standard deviation calculated from all questionnaires. These values are plotted against the simulator settings on a parameter by parameter basis. The ordinate is from 1 (very comfortable) to 5 (very uncomfortable) since all evaluations were made using a five point scale. The comfort results obtained for the four body areas (head/neck region, arms, back and the legs) are not presented here since they were found to follow the overall ratings with few exceptions.

From *Figure 6* it can be seen that comfort worsened with decreasing roof rail height with the exception of the roof rail +2 cm configuration. These results were checked with a Friedman test and are significant with a confidence of 0.05. The results confirm an important rule of thumb used by automobile designers that a lower roof line will make vehicle ingress/egress more difficult. Lowering the roof rail was seen to force the subjects to bend the head and neck more severely, and

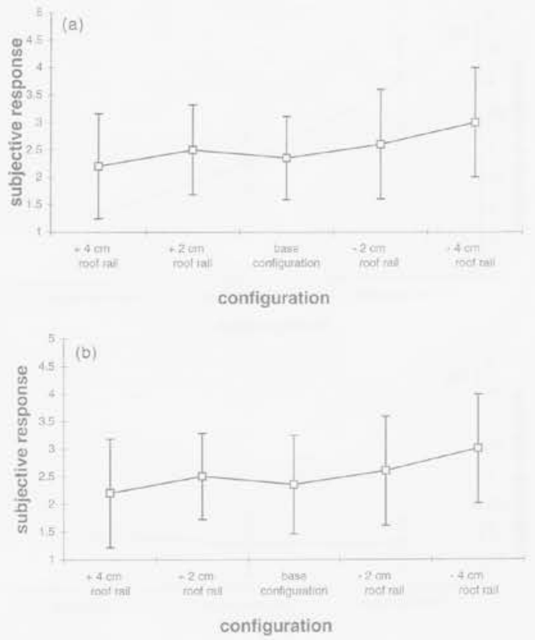

Figure 6 Average subjective ratings and one standard deviation lines for all subjects. (a) Ingress tests of all roof rail configurations. (b) Egress tests of all roof rail configurations

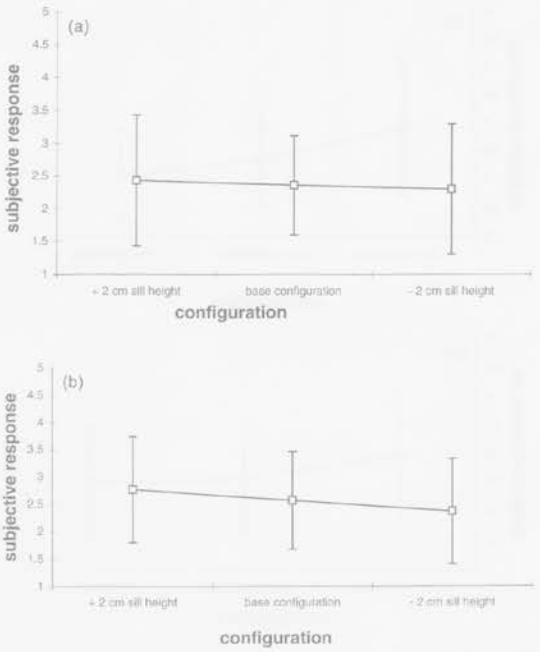

Figure 7 Average subjective ratings and one standard deviation lines for all subjects. (a) Ingress tests of all sill height configurations. (b) Egress tests of all sill height configurations

the questionnaire results suggest that this was strongly translated into perceived discomfort. The roof rail +2 cm configuration was an interesting exception to the trend shown in *Figure 6*. In this case, the combination of door height and roof rail height placed the head motion of most subjects close to the upper corner of the door which is very sharp, a situation which lead to many complaints.

Figure 7 presents the results from the tests in which the sill height was modified. Lowering the sill had a positive effect on ingress/egress comfort, because this provides a lower obstacle over which the legs must be raised. While the tendency is present in the data, it is not pronounced. The questionnaire data suggested that differences existed between the responses of small subjects with respect to the tall subjects. *Figure 8* presents the responses of the smallest five subjects and the tallest five subjects tested in the case of vehicle ingress. The taller subjects gave slightly worse responses when the sill height was reduced, while the shorter subjects gave strongly improved responses. While the questionnaire responses seemed to indicate trends, the results of *Figures 7 and 8* did not result significant at a 10 percent confidence level.

Figure 9 presents the responses from the configurations in which the height of the rear seat was modified ($\alpha = 0.01$). While the data indicate that lowering the height of the seat produced improved comfort ratings, several considerations must be made. The first is that the base configuration of the simulator (the Alfa 155 automobile) had a rear seat height from ground of 56 cm, thus most of the test subjects had to lower their body while entering the automobile. The fact that lowering the seat improved comfort is not intuitive since a lower seat implies a longer journey and

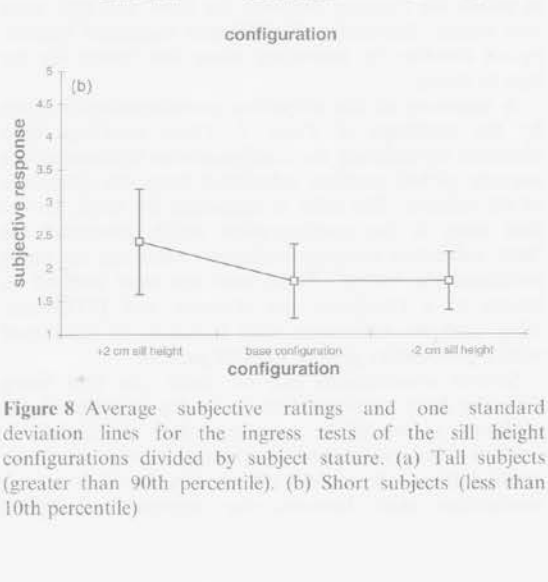

Figure 8 Average subjective ratings and one standard deviation lines for the ingress tests of the sill height configurations divided by subject stature. (a) Tall subjects (greater than 90th percentile). (b) Short subjects (less than 10th percentile)

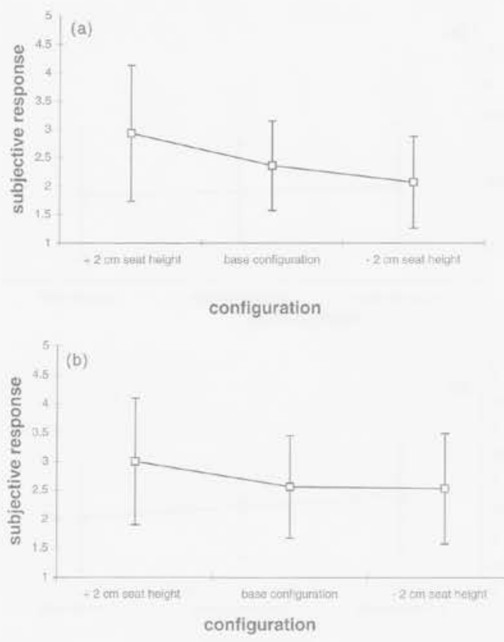

Figure 9 Average subjective ratings and one standard deviation lines for all subjects. (a) Ingress tests of all seat height configurations. (b) Egress tests of all seat height configurations

additional muscular effort. A possible explanation can be formulated by plotting the data for the smallest and tallest five subjects separately. In *Figure 10* ($\alpha = 0.1$) it can be seen that the tallest subjects gave strongly favourable responses to the configurations with low seats while the smaller subjects varied their responses little. Lowering the seat appears to help the taller subjects to lower their body below the roof rail. The current results are therefore only applicable in the case of sedan type cars which require people to lower their body when entering and exiting. Other vehicles such as trucks or MPV's which require people to lift their bodies upwards require further study.

Figure 11 ($\alpha = 0.05$) presents the results from the tests in which the distance between the front and rear seats was varied. Increasing the distance increased ingress/egress comfort by providing more free space for the legs to swing.

A summary of the subjective questionnaires is given by the rankings of *Table 3*. These rankings were obtained by ordering the configurations in terms of the average global comfort calculated from the responses of all subjects. The table is organised by merit, so the first entry is the configuration which produced the 'best' subjective comfort evaluation while the last entry produced the 'worst'. These rankings were verified by means of a Friedman test (Greene and D'Oliveira, 1994) and the differences were found to be significant with a probability greater than 99 percent.

Several observations can be made, the first being that the base configuration is in the middle of the rankings as would be expected since the simulator settings were established by taking steps around this configuration. A second observation is that strong similarities exist between the ingress and egress

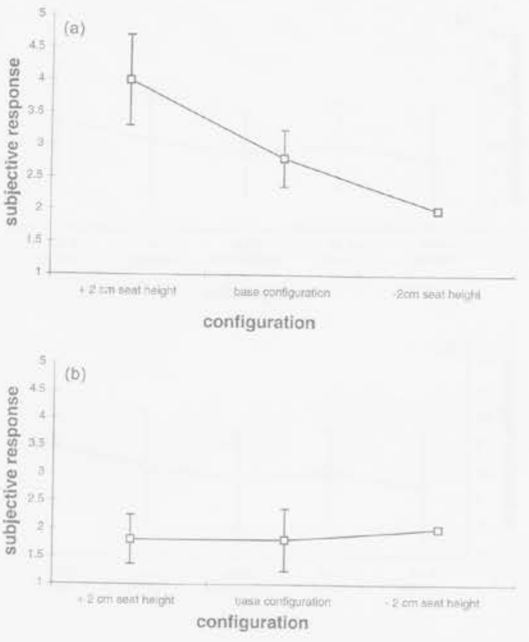

Figure 10 Average subjective ratings and one standard deviation lines for the ingress tests of the seat height configurations divided by subject stature. (a) Tall subjects (greater than 90th percentile). (b) Short subjects (less than 10th percentile)

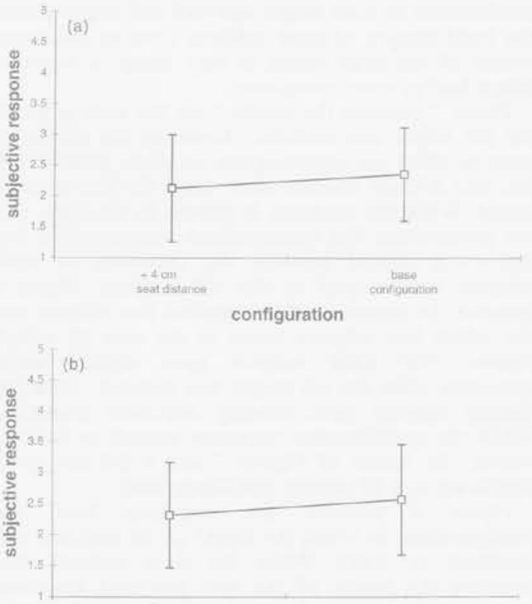

Figure 11 Average subjective ratings and one standard deviation lines for all subjects. (a) Ingress tests of all seat distance configurations. (b) Egress tests of all seat distance configurations

Table 3 Comfort rankings for all simulator configurations tested

Rank	Ingress	Egress
1	Seat height −2 cm	Seat distance +4 cm
2	Seat distance +4 cm	Roof rail height +4 cm
3	Roof rail height +4 cm	Sill height −2 cm
4	Sill height −2 cm	Seat height −2 cm
5	Base configuration	Base configuration
6	Sill height +2 cm	Roof rail height +2 cm
7	Roof rail height +2 cm	Sill height +2 cm
8	Roof rail height −2 cm	Roof rail height −2 cm
9	Seat height +2 cm	Seat height +2 cm
10	Roof rail height −4 cm	Roof rail height −4 cm

Table 5 Number of times each body part was cited as hindering ingress/egress

Body part	Number if times cited in the questionnaires
Head/neck	26
Right foot	17
Left foot	12
Left thigh	10
Right thigh	9
Right shoulder	5
Upper back	3
Left shoulder	3
Lower back	2

rankings, but also differences. This suggests that the two movement situations are sufficiently different as to require separate tests as in the current study. The distance between the front and rear seats appears to be critical towards determining ingress/egress comfort since the seat distance +4 cm configuration is at, or near, the top of both the ingress and egress rankings. The roof rail height was also found to be decisive since the −4 cm configuration is at the bottom of both rankings.

An overview of the importance of each of the simulator components is given by the responses to the question which asked which part of the simulator most hindered ingress/egress. *Table 4* lists the number of times each element of the simulator was cited as hindering ingress/egress, counting the questionnaires from all subjects and all tests. The roof rail and front seat were by far the most troublesome elements.

An overview of where bodily discomfort can occur due to ingress/egress is given by the responses to the question which asked which part of the body was moved with the greatest difficulty. *Table 5* lists the number of times each body part was cited, counting the questionnaires from all subjects and all tests. It can be seen that the head/neck region and the feet are the body parts that are most strained by ingress/egress motions.

A final result from the subjective questionnaires was the response to the question which asked if the simulator was representative of a real automobile in terms of ingress/egress. The simulator was considered realistic by 34 subjects, while 2 were disturbed by the fact that the rear seat lifting mechanism was visible.

Table 4 Number of times each part of the simulator was cited as hindering ingress/egress

Simulator component	Number if times cited in the questionnaires
Roof rail	117
Front seat	105
Sill	63
Door	61
Wheel arch	45
Rear seat	32
Rear pillar	24
Lower front pillar	15
Upper front pillar	14

Iso-comfort surfaces

The roof rail height was found to be one of the simulator parameters which most affected ingress/egress motion. The motion of the vertex marker of the head was found to be particularly sensitive to changes in roof rail height since much of the additional effort involved with passing under a lower door aperture was associated with bending of the neck and upper back. These observations suggested that iso-comfort surfaces might be defined using the motion trajectories of the vertex. These geometric envelope surfaces were defined as the surface under which the vertex marker of the head passed for all the subjects who gave the same subjective rating of the door frame. For example, the data from all subjects who gave a 'very comfortable' rating was grouped together and used to fit a surface. These iso-comfort surfaces provided a method of quantifying the overall comfort associated with a particular value of roof rail height since any frame which is lower than the fitted surface does not manage to produce the indicated level of comfort. A mathematical expression was fitted for each iso-comfort surface over the plane of the simulator. In the most general terms in cartesian co-ordinates

$$z = f(x, y)$$

where f could have been chosen to be any real valued function of x and y. For simplicity, the functional was chosen to be a polynomial expansion of the form

$$z(x, y) = \sum_{m=0}^{M} \sum_{n=0}^{N} C_{mn} x^m y^n$$

where M and N indicate the highest order of the polynomial used. The method of least squares regression was used to calculate the coefficient values. The least squares approach formulates an error function of the form

$$\chi^2 = \sum_{i=1}^{N_p} \left[z_i - \sum_{m=0}^{M} \sum_{n=0}^{N} C_{mn} x_i^m y_i^n \right]^2$$

where N_p indicates the number of experimental data points used for the regression. The minimum value of ^{2} occurs where the derivative with respect to all parameters vanishes. Therefore the optimal c_{mn} are found from

$$\frac{\partial \chi^2}{{}_{mn}} = 2 \sum_{i=1}^{N_p} \left[z_i - \sum_{m=0}^{M} \sum_{n=0}^{N} c_{mn} x_i^m y_i^n \right] \left[\sum_{m=0}^{M} \sum_{n=0}^{N} x_i^m y_i^n \right] = 0$$

which yields the system of equations

$$\sum_{i=1}^{N_p} \left[\sum_{m=0}^{M} \sum_{n=0}^{N} (x_i^m y_i^n)^2 \right] [c_{mn}] = \sum_{i=1}^{N_p} \left[\sum_{m=0}^{M} \sum_{n=0}^{N} x_i^m y_i^n z_i \right]$$

which in matrix notation is of the form

$$[\mathbf{S}][\mathbf{c}] = [\mathbf{Z}]$$

where $\mathbf{S}$ is a system matrix of order N_p by MN, $\mathbf{c}$ is a coefficient vector of N_p length and $\mathbf{Z}$ is a vector of weighted vertical values of length N_p. Application of the above to experimental data often produces singular valued matrices for which inversion is not possible. The method chosen for circumventing this problem was to first perform a single value decomposition (Press *et al*, 1989).

Figure 12 presents two of the iso-comfort surfaces fitted. The first was obtained by grouping the vertex trajectory data for all the subjects who responded that the door frame was 'very comfortable' while the second was obtained from all the subjects who responded that the configuration was 'very uncomfortable'. The surfaces were fitted using the data for the area in the immediate vicinity of the door frame, from all configurations tested. It can be seen that there is a fold, or minimum, in both surfaces which occurs at the point where the subjects bend the most when entering the simulator (roughly along the line $y = -20$). This minimum was found to be located outside the automobile at 2–3 cm from the plane of the door frame. As a general observation, surfaces associated with the comfortable rating were generally smoother than surfaces associated with the uncomfortable rating. A possible explanation is that the surfaces become more complex due to abrupt changes in motion caused by twisting and bending of the test subjects as they enter the smaller aperture with difficulty. The regression equation for the 'very comfortable' surface of *Figure 12* is

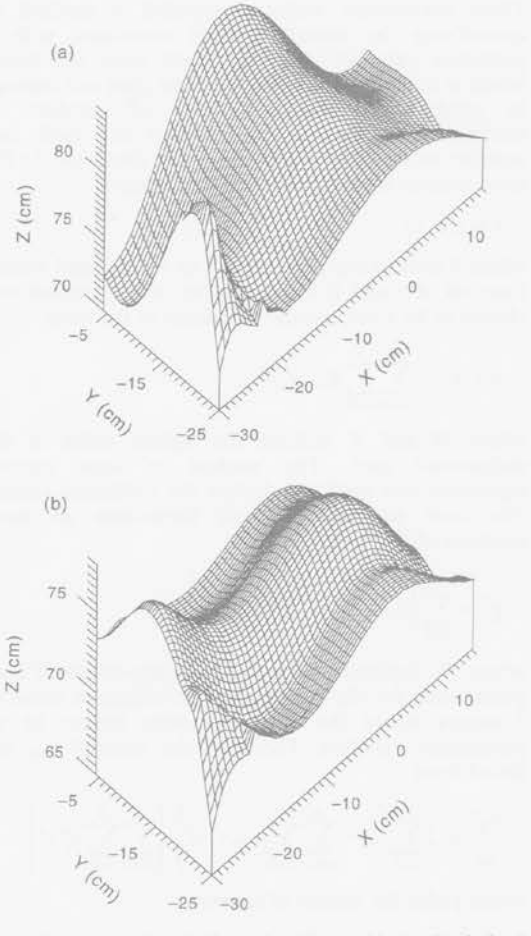

Figure 12 Iso-comfort surfaces for those subjects who judged the door frame to be (a) 'very comfortable', (b) 'very uncomfortable'

$$\begin{aligned} Z = {} & 0.784 - 0.865x - 1.363y - 41.033y^2 + 23.581x^3 \\ & + 81.356xy^2 - 455.686y^3 - 29.373x^4 \\ & - 17.216x^2y^2 + 668.597xy^3 - 2183.648y^4 \\ & - 233.963x^5 - 385.542x^3y^2 + 1715.144xy^4 \\ & - 3755.771y^5 \end{aligned}$$

while the equation for the 'very uncomfortable' surface is

$$\begin{aligned} Z = {} & 0.755 - 2.818x^2 - 27.730y^2 - 7.326x^3 \\ & + 0.566x^2y - 12.440xy^2 - 516.215y^3 \\ & + 48.553x^4 + 22.448x^3y - 149.086xy^3 \\ & - 3156.221y^4 + 151.735x^5 + 8.317x^3y^2 \\ & - 346.608xy^4 - 6233.643y^5 \end{aligned}$$

The equations given above are expressed in centimetres with the origin of the co-ordinate system set at the H point (Society of Automotive Engineers, 1989) of the rear seat. In all cases studied, accurate modelling required the use of polynomials up to fifth order. Lower order polynomials were not sufficient because of the irregular nature of the envelope surfaces which show little or no symmetry about either the X or Y axis of the simulator.

Figure 13 presents plots obtained by cutting the iso-comfort surfaces of *Figure 12* along planes parallel to the X and Y axis. The first was obtained by cutting along a plane formed by all values of X for which Y is equal to -19.75 cm. This plane is located just outside the door frame near the point of maximum bending of the test subjects. It can be seen that there are 3 or more centimetres separating the two surfaces. The second plot was obtained by cutting the surfaces along a plane defined by all values of Y for which X is equal to 21.25 cm. This plane crosses the rear seat just forward of the H point. It can be seen that the two comfort levels are separated by a value typically greater than 2 cm. The height differences between the two surfaces can be considered statistically significant since the one standard deviation value calculated from the vertex motion data used to fit the surfaces was found to be 1.6 cm on average.

Discussion

An important observation that can be made based on the current results is that the effect of the design parameters depends on the stature of the test subjects. Several instances were found where small subjects had different problems than the tall subjects for the same configuration. Any door frame design will thus be a compromise between the contrasting requirements of the two user groups rather than a universally optimal

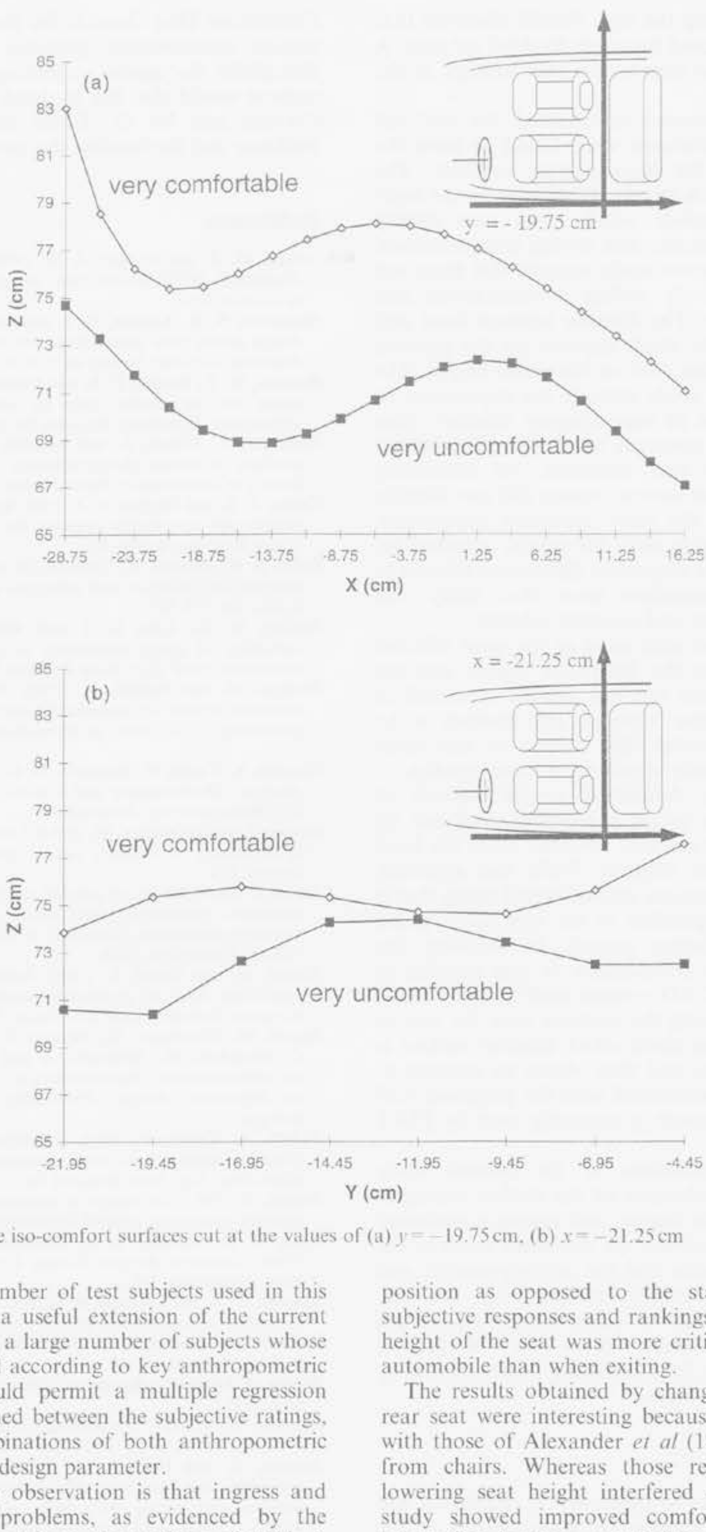

Figure 13 Sections of the iso-comfort surfaces cut at the values of (a) $y = -19.75$ cm, (b) $x = -21.25$ cm

configuration. The number of test subjects used in this study was small, but a useful extension of the current study would be to use a large number of subjects whose data could be grouped according to key anthropometric dimensions. This would permit a multiple regression analysis to be performed between the subjective ratings, and the various combinations of both anthropometric dimension and vehicle design parameter.

Another interesting observation is that ingress and egress are different problems, as evidenced by the subjective responses and from the rankings of *Table 3*. Sill height, for example, seems more critical in egress than in ingress. The comments of the test subjects indicated that this was due to the greater difficulty in lifting the leg over the obstacle from the seated position as opposed to the standing position. The subjective responses and rankings also showed that the height of the seat was more critical when entering the automobile than when exiting.

The results obtained by changing the height of the rear seat were interesting because they are in contrast with those of Alexander *et al* (1996) relative to egress from chairs. Whereas those researchers found that lowering seat height interfered with seat egress, this study showed improved comfort. This suggests an interaction between seat height and roof rail height. Lowering the seat provides more space for movement, as noted in the study by Petzäll (1995). This is particularly relevant for those subjects whose entry strategy is to back into the car and transfer weight to the seat before rotating the legs. Petzäll observed that this strategy was adopted by many disabled subjects. A few subjects were also seen to use this strategy in the current study.

Of the design parameters investigated, the roof rail height and the seat distance were found to have the greatest impact on the ingress/egress comfort. The height of the roof rail is largely determined by the body shape of the automobile which is in turn greatly influenced by aerodynamic and styling considerations. The results of the current study suggest that there are trade-offs between body styling considerations and ingress/egress comfort. The distance between front and rear seats is a variable which depends on the position of the driver's seat, but also on the cabin length. The results of the current study indicate the importance of cabin length in terms of ingress/egress comfort, thus adding to traditional concerns relative to the postural comfort of the rear seat occupant. An interesting observation is that the current results did not identify sill height as one of the most important parameters. This contrasts somewhat with the results obtained by Petzäll, and may imply important differences relative to the test subjects themselves since that study was conducted using elderly and disabled subjects.

The body parts that were cited as the most affected by ingress/egress were the head/neck region and the feet. While foot motion was not directly measured in this study, the subjective responses and analysis of the VHS recordings indicated that motion of this body part should be accurately measured in future studies.

The current study defined a simple method of evaluating the design of an automobile roof rail by means of iso-comfort surfaces obtained from the head trajectories of the test subjects. While this approach has a number of limitations (the principal being that it is only rigorously applicable to the roof rail), useful insights were nonetheless gained. By defining the surfaces by means of polynomials, it was possible to insert them into the CAD systems used by automobile designers. By positioning the surfaces over the seat H point, the designer can check which comfort surface is cut by the door frame, and thus obtain an estimate of the average comfort associated with the proposed roof rail height. This approach is currently used by FIAT designers.

Possible future extensions of the current study include: a detailed evaluation of the motion strategies involved in automobile ingress and egress, a statistical correlation analysis between the responses given to the subjective questionnaires and the anthropometric and simulator parameter values, extension of the iso-comfort surface concept to other design parameters such as distance between seats, and the use of biomechanical models for calculating centre of gravity motion and muscular forces.

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