ERGONOMIC MODELING AND EVALUATION OF AUTOMOBILE SEAT COMFORT

by

Mike Kolich

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ABSTRACT

This research work is geared toward proving that automobile seat comfort, which is a subjective construct, can be predicted from objective measures. This type of forecasting ability would effectively improve the efficiency with which seats are designed. Presently, seats are developed in an iterative manner because subjective feedback drives the design. Iteration requires time and costly prototypes. This could be justified if the process guaranteed a comfortable seat. Unfortunately, this is not the case.

Even with numerous technologies available, the automotive seating industry has had limited success quantifying comfort. The problem stems from the lack of a scientific method. This deficiency was addressed through the creation of a repeatable data collection protocol for seat interface pressure measurement.

Seat comfort cannot be quantified without an understanding of the consumers' likes and dislikes. The best way to obtain this information is to gauge perceptions of comfort through a survey. This research is significant in that it (1) provides a survey with acceptable levels of reliability and validity and (2) defines an overall comfort index.

The overall comfort index was used as the dependent variable in a prediction model. This would not be a viable undertaking without a reliable and valid survey. Using a stepwise regression procedure, the link between objective measures and subjective perceptions was established and validated. From the model, human criteria for seat interface pressure parameters were established. The model also demonstrated that appearance was related to comfort.

Due to the lack of emphasis on the educational side of automobile seat usage, drivers are not fully realizing the comfort-enhancing benefits of seat adjusters. This study, in addition to providing direction on

how to adjust the seat for maximum comfort, presents and validates a model to predict driver selected track position as a function of occupant demographics and anthropometry.

If this research is to affect design practices, direction on how to impact the objective measures of comfort is required. To this end, seat geometry and contour design guidelines were derived. These guidelines represent an important advancement in the body of knowledge dealing with automobile seat comfort.

DEDICATION

To my parents, Mike and Metka Kolich.

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1. INTRODUCTION

Many major automobile manufacturers still fail to be pro-active in their considerations for the people who purchase their products (Porter, 1994). In the early 1980's, the familiar slogan 'safety does not sell cars' was believed to be true by many manufacturers, and maybe it was. The last decade has seen a large increase in public awareness concerning developments in primary and secondary safety and a quick browse through any car magazine shows that safety features take pride of place. Similarly, society's attitudes toward comfort are beginning to change - not only in the home and office, but in the automobile as well. In other words, comfortable seating is no longer considered a luxury; it is a requirement.

Rising customer expectations are, therefore, forcing the automotive seating industry to focus design efforts on occupant comfort. Unfortunately, comfort, as it is currently understood, is a subjective concept that is difficult to measure. The automotive seating industry has thereby been challenged to define comfort in an objective manner. In fact, the quantification and subsequent design of automotive seating for improved occupant comfort is, presently, one of the primary goals for seat system design teams. This task is complicated by such factors as user subjectivity, occupant anthropometry, seat geometry, and amount of time spent sitting (Thakurta et al., 1995). Also complicating matters is the growth of the international automotive market that has served to increase diversity in seat design. In other words, unique, but functionally equivalent, seats are required to satisfy different comfort criteria.

Due to the lack of proven analytical measurables, the seating industry relies on jury evaluations as the main measure of seat comfort. The jury evaluation methodology usually involves highly structured surveys that direct occupants to assign feelings of discomfort to specific regions of the seat. The nature of the jury evaluation methodology makes it is necessary to investigate the opinions of relatively large groups of passengers in order to determine the impact of various design features on perceived seating comfort (Manenica and Corlett, 1973). This trial and error approach is very time consuming, expensive, and prone to measurement error.

1.1 Thesis

The thesis is that automobile seat comfort, which is undeniably a subjective construct, can be quantified. If true, the design process should yield more comfortable seats in a more efficient manner. Efficiency being measured in terms of cost and development time (i.e., time-to-market).

1.2 Deliverables

This manuscript's contribution can be divided into five areas (all of which are related to the previously outlined thesis). They are:

1. A reliable and valid survey for the assessment of subjective perceptions of automobile seat comfort. This includes the definition of an overall comfort index derived from survey responses.
2. A scientific method for the evaluation of automobile seat comfort.
3. A greater understanding of driver selected seat position as demonstrated through a prediction model and a discussion regarding how to adjust an automobile seat for maximum comfort.
4. A model to predict the overall comfort index as a function of automobile seat interface pressure, occupant anthropometry, occupant demographics, and perceptions of automobile seat appearance.
5. Automobile seat geometry and contour design guidelines that consider (a) available anthropometric data, (b) automobile seat interface pressure characteristics, and (c) subjective perceptions of automobile seat comfort.

2. LITERATURE REVIEW

2.1 Definition of Automobile Seat Comfort

Although there exists substantial research in the field of comfort, these investigations have generally occurred in a microcosm. Since published definitions reflect the disciplines of the researchers who formulated them, there is no universally accepted operational definition of comfort (Lueder, 1983). To further this discussion, there is little agreement as to whether comfort and discomfort should be regarded as being a bipolar continuum or as composing two experiential dimensions. Hertzberg (1972) first operationally defined comfort as "the absence of discomfort". Everyone has experienced the positive state of comfort. However, whether automobile seats can induce this state is still open to debate. To a certain extent, the debate becomes entrenched in semantics since a relief from discomfort may be experienced as a positive state of comfort. Discomfort has, however, been addressed more frequently because its objective correlates are considered to be more tangible.

Richards (1980) has suggested that comfort is a bipolar dimension that can be attributed to characteristics of design. Evidence to support this claim comes from the fact that people, when given the opportunity, rate their subjective responses across an entire continuum, ranging from positive comfort to discomfort. For this research work, comfort, unless specified, will be considered a representation of both positive comfort and discomfort. The term discomfort will be used only when the discussion is confined to the assessment of that construct.

In terms of dictionary definitions, Funk & Wagnalls (1979) defines comfort as a state of mental or physical ease. According to Lueder (1983), some dictionaries define comfort as "the provision of support and assistance". Comfort relative to automobile seating might, therefore, be viewed as a function of the patterns of physical supports and constraints on the occupant engaged in the task of driving. As such, comfort may be represented physiologically, psychologically, behaviorally, and in performance.

The pursuit of an all-encompassing definition of comfort will, in all likelihood, never end. This dissertation acknowledges this fact and will, simply stated, consider occupant comfort a consensually held construct (i.e., a large group of representative subjects perceive the seat in a similar manner) that can be manifested objectively (i.e., consistently quantifiable). At the fundamental level, regardless of how comfort is represented, automobile seat design teams must attempt to minimize the level of discomfort or maximize the level of positive comfort. This is undisputable. For this reason, the definition outlined in this paragraph can, and will be, considered sufficient.

2.2 Current Automobile Seat Comfort Development Process

The typical approach to automobile seat comfort development is to first select a target from the appropriate vehicle segment. The target is usually selected through the joint efforts of marketing and engineering. The decision is, many times, based on consumer experiences with recently launched products. In this regard, J.D. Power & Associates' Annual Seat Quality Report is extremely popular. J.D. Power & Associates provide a supplier-focused analysis describing consumer experiences with the quality, design, comfort, and features of their automotive seats. By tying model-level information to specific seat suppliers, J.D. Power & Associates is able to provide comprehensive quality data about the seating industry, while offering suppliers a means of tracking end-user opinions of their products. This data is used to help assess a company's competitive standing within the seating industry. Target selection is not focused as much on the seat supplier or the seating industry as it is on the individual seats standing relative to other seats in the same market segment.

The target vehicle is purchased and retained throughout the development process. This helps to insure that the target is consistent (by eliminating production and build combination variations). The target seat is then benchmarked. As part of this exercise, a subjective evaluation is performed. This feedback, in terms of things gone right and things gone wrong, is used to drive comfort development for the remainder of the program. That is, prototypes are built and evaluated using the same subjective evaluation approach. More specifically, the target seat is evaluated against the next generation seat until the new program seat meets or exceeds the comfort level offered by the target seat. The purported strength of this process lies in the A to B comparison of seats. Since a typical seat program takes 3-4 years to execute, by the time the product is launched it is just as comfortable as the best seat in the market 3-4 years ago. The excessively long development time hinders advances in comfort.

It is standard practice, in the automotive seating industry, to perform subjective evaluations as part of an extended duration ride & drive. The recommended duration is two hours. This typically allows for four rotations per day (excluding breaks and lunch between rotations). Anything over two hours makes for a long day of travel. In addition, anything over two hours becomes uncomfortable for many ride participants for reasons other than the seat. The break is thought to be a critical part of the ride & drive process and is designed for a minimum of 15 minutes. By walking around during the break, the body is refreshed in preparation for the next seat, minimizing the carry over effects of the previous rotation. This is, however, debatable.

The length of the ride & drive is dependent on how many ratings per seat the design team feels are necessary to yield meaningful results. With a maximum of four rotations per day, it is only possible to get four people to evaluate one seat in a day. This is too small a number to yield worthwhile results. It is recommended that the ride & drive be at least two days in length and even with that, there should be two samples of each new seat whenever possible within the rotation. This gives 16 ratings per seat and can help to reduce the effects of differences between vehicles that may not be possible to avoid.

A two-hour rotation also allows three meaningful ratings to be obtained. There are three general ratings that are recommended for use in seat comfort evaluations: 10 minute, one hour, and two hour. The 10-minute evaluation is meant to represent the showroom appeal of the seat while the one and two-hour ratings are meant to assess long-term comfort. Although difficult to control, ride & drive coordinators commonly ask that the ratings be based on perceptions and expectations of the market segment. The ratings typically range from one (uncomfortable) to five (comfortable) in half step increments. Design teams may wish to compute an 'overall' or 'average' seat rating by combining the responses from the above categories. This number could, however, be confusing since seat comfort parameters are thought to change dramatically over time. In other words, a seat that is initially comfortable may not necessarily be comfortable after an extended period of time.

At the conclusion of each leg of the ride & drive, in addition to providing a general numeric rating, participants are required to evaluate specific areas of the seat through a structured survey. At this point, participants also have the opportunity to make written comments. These specific comments should reflect the participant's final impression of the seat. Within the specific ratings, it is possible to combine those that pertain to the cushion to yield an overall result for the cushion. The same can be done for the seatback. This can allow comparisons from cushion to cushion and seatback to seatback independent of the rest of the seat. The risk is that the cushion design can affect perceptions of seatback comfort or vice versa.

In addition to the structured survey, verbal comments are collected through the use of a trip radio. The ride coordinator collects verbal comments from each participant at the 10-minute, one hour, and two hour mark. The comments are captured by a designated note-taker (equipped with a lap-top) and a tape recorder. The tape recorder and note-taker are usually in different vehicles to minimize the loss of comments.

It is not uncommon for a program to require 15 ride & drive iterations to meet or exceed the comfort level offered by the target seat. Early development requires mule vehicles (modified, if possible, from current production) that simulate the intended direction of the chassis dynamics. As an aside, of all vehicle components, the chassis has one of the longest lead times. The mule vehicles are essential because they allow for early seat contour, seat suspension, and trim cover development. As the development proceeds, the latest level seats should be provided for the chassis development vehicles and, finally, production level vehicles.

The seat comfort development process requires a core team of participants ranging from 5th percentile females to 95th percentile males (stature). Ideally, the team would be skewed to represent the target buyer demographics and anthropometry. Unfortunately, for fear of limiting their sales potential, vehicle manufacturers rarely identify a target population. Hence the recommended 5th to 95th percentile range. The core team should also consist of key stakeholders of the seat system. To minimize variations of input data, each team member must be committed to the process for the duration of the program. This is, very often, difficult to achieve.

Program complexity is another factor that complicates this process. In other words, the seat comfort development process requires the evaluation of all seat types (i.e., full bench, split bench, and bucket), content (manual or power adjuster, manual or power recliner, adjustable or fixed head restraint, etc.), features (manual or power lumbar, front and/or rear cushion tilt, seat heaters, etc.), trim styles (i.e., base level, mid level, and up level), and fabrics (i.e., cloth, vinyl, leather) available for a particular platform that may include several marketing divisions. Manual transmissions are also a significant subset of certain vehicle lines. The operation of a manual transmission may create unique comfort requirements for the driver. Therefore, where appropriate, each major seat design configuration should be evaluated in a manual and automatic transmission environment. The number of vehicles required for a given ride & drive is based on all of these considerations.

For extremely large programs, it is not uncommon to have 150 different seat configurations. With this type of complexity, it is impossible to evaluate (through a single ride) every possible combination. For this reason, initial seat comfort is very often performed on high vehicle volume seats (to the detriment of lower vehicle volume seats). This is a huge disadvantage. Once an acceptable level of comfort is achieved for the high volume seats, other combinations are evaluated to ensure that comfort is not compromised. This usually involves an evaluation of different trim styles. Trim styles typically differ in terms of seam locations. If, for example, a seam in a particular trim style is located in a region that could deteriorate seat comfort, efforts should be taken to relocate the seam. Unfortunately, by the time the trim style in question is included in a ride & drive, it may be too late to change the design without incurring significant costs.

Another problem with this process is that design direction, early in the program, is based on feedback obtained from seats comprised of skived foam and unrepresentative hardware. Skiving is the process of mechanically shaping a foam pad by cutting it out of block or sheet stock. Skived foam does not, in any way, feel like molded foam due primarily to differences in occupant penetration. It should, therefore, not be used to direct decisions regarding cushion length, cushion width, lumbar location, etc.. Hardware refers to the handles, switches, and controls used to operate the seat. Unless the production level hardware is used, it is unfair to evaluate functionality (locations, efforts, etc.) with respect to the seat system. Once again, design decisions, based on ride & drive feedback, should be withheld. Molded foam and representative hardware are, unfortunately, not available early in the process.

The process is also rendered ineffective by the fact that the seat interacts with the vehicle system, particularly the interior environment. Vehicles, just like seats, undergo product development cycles. As a result, the power-train, vehicle suspension, and package characteristics (pedal locations, steering wheel position, etc.) are, very often, not finalized until production. This, obviously, affects seat comfort development.

The entire process is outlined in Figure 1.

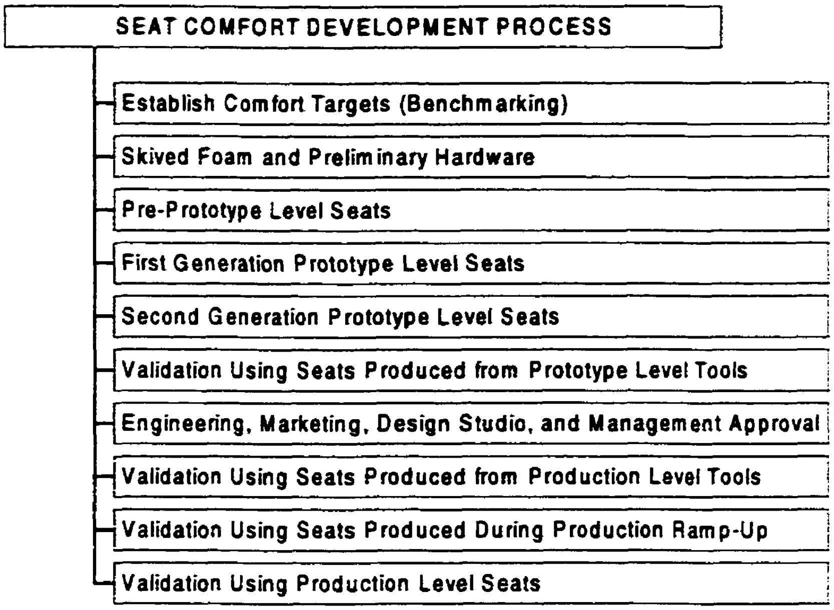


Figure 1: Flow Chart for Typical Seat Comfort Development Process

Each step in this process corresponds to a ride & drive and is typically considered a program milestone. In reality, several working level rides may be needed before the seat system is ready to exit a particular developmental phase.

In summary, the current process is an inefficient and outdated way to develop a comfortable automobile seat. It is extremely time consuming (if the key stakeholders in the seat system are spending all this time riding, they are, obviously, not developing the product) and expensive (excessive changes lead to tooling iterations). It should also be noted that recent advances in seat comfort evaluation technologies are not reflected in this process. These limitations could, in some ways, be justified if the process could guarantee a comfortable seat. This is, unfortunately, not the case. Since good seats are the exception and not the rule, the seat comfort development process needs to be overhauled.

2.3 Automobile Seat Comfort Survey

Customers evaluate automobile seat comfort in very subjective ways. This, obviously, complicates seat design. To circumvent this complexity, the common belief is that seat system design teams desperately need objective, measurable laboratory standards that can be linked to subjective perceptions of comfort. Only in this way, can a decision be made regarding whether or not a particular design will be viewed by the customer as comfortable. For this reason, the automotive seating industry has been working towards quantifying comfort through various methods.

Quantification methods are, however, meaningless without an understanding of what occupants perceive as comfortable. Admittedly, the best way to obtain this understanding is through the administration of surveys. A properly designed survey is paramount because it affords the seat system design team an instrument from which to develop prediction models and formulate guidelines. A review of the published literature in the area of seat comfort reveals that this instrument does not, presently, exist. This is surprising given the extent to which seat comfort development relies on survey data.

It should, also, be noted that the importance of survey data are not expected to be diminished by the ability to predict comfort. The reason is that perceptions of comfort will, almost definitely, change with time. As perceptions change and new measuring techniques are developed, surveys will be required to update prediction models and guidelines.

Currently, seat comfort surveys are, typically, subjected to some form of quantitative analysis, whether it is a simple frequency count or a more complex statistical treatment. The results are then used as the basis for design decisions. The method of quantification, therefore, requires careful consideration. According to Brigham (1975), this must occur in two stages. First, the survey must be designed so that the data are in a suitable form for the analysis and are free from the effects of bias. Secondly, when the analysis itself is conducted, the exact nature of the data and the conditions under which it was collected must be considered, to ensure that the analysis is statistically appropriate.

Despite the fact that many of the problems related to the collection of subjective data have been well known for some time, the quantitative aspects of survey design and analysis are frequently given too little attention (particularly in the automotive seating industry). As a consequence, the survey may provide results that are, at best, biased and, at worst, totally invalid. This is, unfortunately, the case in the automotive seating industry. Hence, comfort development takes on a trial and error approach. Needless to say, this is an expensive and inefficient way to impact design.

Most seat comfort surveys require the respondent to give either a factual answer or to make a judgement. In either case the wording of the survey items has a considerable effect on the results obtained and it should, therefore, be considered very carefully (Oppenheim, 1966). One of the more important principles is to avoid ambiguity. This may require more care than at first might be thought.

The interest and motivation of the respondent is another critical factor that should be reflected in both the design of the overall survey and the wording of the individual items. The practical implication is that both the length and content of the survey must be appropriate to maintain the interest of the respondent, otherwise valuable information may be lost and spurious responses introduced.

It is also imperative to devote special attention to the design of the rating scale. As seat comfort is multidimensional, inappropriate scales may elicit ratings on some subjective trait other than comfort. Among the factors that must be considered are the type of scale (numeric or graphic) and the number of categories (coarseness or fineness of the scale) (Guilford, 1954). The number of categories in the scale must match the respondents' ability to discriminate in his/her response to the item. If an insufficient number of categories are used, valuable information will be lost. On the other hand, if too many categories are used, no amount of statistical manipulation will get information out of the data that has not been put into it by the respondent. Some psychological research suggests that, for most people, the upper limit for ranking is approximately seven categories (Grigg, 1978). Grigg (1978) claims that scales with more than nine categories do not lead to a significant increase in information regarding the items rated. He does, however, acknowledge that respondents familiar with the scaling method and the stimulus material (i.e., experts) may be able to use a larger number of categories.

Verbal tags attached to the categories are sometimes the source of ambiguity. When verbal tags are used it is important to take care in selecting the words and phrases used to represent positions on the scale. Osgood et al. (1957) were among the first to test the meanings of qualifiers used in verbal scales. With respect to the meaning and strength of such qualifiers, Bartram and Yelding (1973) performed arguably the most comprehensive study. They sought to discover the positive or negative strength that respondents ascribed to different words generally in use to find out which of them have the most clearly defined meaning across the population as a whole. The study found that respondents appeared to be most decisive and in agreement with one another when scoring positive extreme values. It was also found that respondents were most confused in the middle points of the scale. 'Almost' and 'slightly' were found to be confusing and imprecise in meaning. Seat comfort surveys should, therefore, avoid these qualifiers. Verbal tags are an extremely important consideration in survey construction.

When rating scales are used so that respondents can indicate, for example, their degree of preference for a particular seat design and numerical scores are assigned to the scaled positions, the question, inevitably, turns to the meaning that can justifiably be attached to the score. In a more general sense, Stevens (1946) and later Cozby (1989) approached the question by defining four levels of measurement which, in increasing order of measurement sophistication, were nominal, ordinal, interval, and ratio.

Nominal scales have no numerical or quantitative properties. An obvious example is the variable of gender. Even if numbers were assigned to the groups, the numbers would be meaningless, except for identification. Ordinal scales are slightly more sophisticated than nominal scales because they involve quantitative distinctions. An ordinal scale produces only a ranking of the characteristic being measured and carries no implication of distance between scale positions. Any set of numbers maintaining the order could be assigned to the scale positions. In an interval scale, the differences between the categories on the scale are meaningful. Specifically, the intervals between the categories are equal in size. The difference between 1 and 2 on the scale, for example, is the same as the difference between 2 and 3. The zero point on such a scale is a matter of convenience but, with a fixed origin or zero point, a ratio level of measurement is obtained. Examples include many physical measures, such as length, weight, or time. Ratio scales are used when variables that involve physical measures are being studied. However, most variables are less precise and so use nominal, ordinal, or interval scale measures.

Most automobile seat comfort surveys use ordinal scales. Knowingly or not, seat system design teams, due to the sophisticated manner in which they statistically treat survey data, are, basically, assuming that the survey items are being measured on an interval scale. This is controversial because the arithmetic operations that can be legitimately performed depend upon the type of rating scale, and this in turn decides what statistical techniques can be employed. For ordinal scale data, Stevens (1946) strongly suggests the application of non-parametric statistical techniques (ranking tests or order tests), which require fewer assumptions regarding the data. Seat comfort survey data is rarely analyzed in this manner. Parametric statistics, on the other hand, which involve addition, multiplication, and division of scale scores, are allowed when the item has been measured on at least an interval scale. According to Siegal (1956), if the assumptions underlying the use of parametric tests, for example the t-test (mean comparison) or F test (variance comparison), are not met then it is possible to question the power of the test. The power of the test is defined as the probability of rejecting the null hypothesis when it is, in fact, false. It is also difficult to estimate the extent to which a probability statement about the hypothesis in question is meaningful when that probability statement results from the unacceptable application of the test.

Prytulak (1975) has produced a critique of Stevens' theory of measurement classification. The critique, citing a number of examples that are incongruous with Stevens' classification, concludes that the theory should be rejected outright. Labovitz (1970, 1972), similarly, argues against strict and blind adherence to rules linking specific statistics to particular levels of measurement and particularly the four scale types of nominal, ordinal, interval, and ratio. Labovitz (1970, 1972) believes that, except for extreme situations, interval statistics can be applied to any ordinal level variable. Although error is introduced this can be offset by the use of more powerful and better-developed statistics. Lord (1953) and Taylor (1968) also dispute whether the strict rigor suggested by Stevens is necessary. In fact, they hold that parametric tests require no assumption at all about the underlying metric. This, in effect, supports the contention that ordinal scale data can be analyzed using parametric statistics.

In this context, Boneau (1960) examined the effects of violations of the assumptions underlying the t-test and F test. These parametric tests, which are commonly applied to seat comfort survey data, assume that the observations are independent, that they are drawn from populations with a normal distribution, and that the sample variances are equal. Boneau (1960) stated that the use of the t-test will result in probability statements that are accurate to a high degree even though the assumptions of homogeneity of variance and normality of the underlying distributions are untenable. Conditions which should be met are (a) the two sample sizes are equal or nearly so and (b) the assumed underlying population distributions are of the same shape or nearly so (if the distributions are skewed they should have the same variance). If these conditions are met, with a sample size as small as 15, the percentage of times the null hypothesis will be rejected when it is actually true will tend to be between 4 – 6% when the nominal value is 5%. If the sample sizes are unequal, then the variance should be equal. Inaccurate probability statements will, however, be produced if there is a combination of unequal sample sizes and unequal variances. These rules also apply to the F test. Boneau (1960) concluded that the t-test and F test are remarkably robust. Robustness is defined as the property of a measure to remain relatively unaffected by changes from standard conditions. Thus, tests that remain practically valid over a wide range of conditions are said to be robust. His argument also supports the use of parametric statistics with ordinal scale data.

Following the same line of reasoning, Anderson (1961) thinks that ordinal scales are as able as interval scales to meet the necessary assumptions. The implication is that researchers should have no hesitancy in computing t, F, or r for most data, especially when equal samples with more than 25 or 30 people are used.

2.4 Driver Selected Seat Position

Humans search instinctively for the body posture allowing the lowest expenditure of energy within the limits of that which is physiologically and biomechanically possible, as well as that which allows an ease and efficiency in task execution (Judic et al., 1993). Driving is, in fact, a task. The vehicle interior should, therefore, be considered a workstation – the driver's seat as one constituent element. The posture ultimately adopted is a compromise between what is good and what is practical.

This fact leads automobile seat system design teams to speak of the posture of least discomfort. It is impossible to quantify automobile seat comfort without first defining a space in which a postural compromise is possible. The seat adjusters, in combination with the anthropometric characteristics of the occupant, help to define this space.

Seat adjustments are supplied to provide some customization of the interior environment to the preferences of the occupant. The minimum set of adjustments for passenger cars is the track, which adjusts the fore-aft position, and recliner, which adjusts the seatback angle. This type of adjustment is necessary to improve not only comfort, but also safety – sitting properly supported and in a relaxed fashion makes the driver more capable of a quicker response.

With respect to the previously described seat adjustments, some basic research has already been conducted. Unfortunately, the results are inconclusive. For example, there is debate as to a required range for track adjustment. Grandjean (1980) recommends a track travel of about 150 mm. This can be contrasted with data collected at the University of Michigan's Transportation Research Institute that suggests 200 mm or more may be necessary to accommodate short and tall drivers (Schneider and Manary, 1991). According to Reed et al. (1994), the seatback recline mechanism should allow torso angles up to 30° (measured from vertical) with a larger range preferred.

Automobile seat adjustment, for the purpose of enhanced occupant comfort, has experienced a rapid introduction of new technologies. For example, Textron's adaptive seat (which is offered as an option on the 1998 Cadillac Seville) offers 8-10 pneumatic and electromechanical adjustments located between the seat structure and soft trim. These adjustments are placed around the bottom of the cushion, lumbar support, and side bolsters. After the ignition is turned on, the seat activates to inflate around the driver gently holding him/her in place. For this feature to be truly beneficial, individual preferences in adjustment need to be understood and accommodated.

BMW has incorporated a different technology, equally impressive in terms of technical content, for some 7-Series models. Called the Active Seat, the technology consists of two liquid-filled containers positioned in the seat base. The containers are alternatively filled and emptied hydraulically to cause a raising and lowering of the right and left sides. This imparts a gentle rocking movement of the pelvis that is said to reduce body tension. Just as with the previously described pneumatic and electromechanical adjustments, for maximum benefit occupant preferences in the rate of rocking need to be considered.

These examples are from a complete seat perspective. Driver selected seat position is also an issue at the component level. More specifically, it is known that, in order to accommodate differences in anthropometry and personal preferences, lumbar support adjustment (in terms of height and prominence) is desirable (Andersson et al., 1974). Complicating matters is the fact that lumbar mechanisms are now being designed to provide massage. Research in this area is focused on control system settings that demonstrate the comfort enhancing ability of the technology (Mohamed, 1996). Based, at least partly, on the strength of these results, the technology should become more and more common. At some point, occupants will demand the ability to adjust the control system settings to achieve their so-called "comfort position". Due to the complicated physiology and biomechanics being addressed by this technology, occupants will, probably, not be capable of maximizing comfort on their own. It is the automotive seating industry's obligation to provide this information.

If properly adjusted, these seat features provide a great deal of freedom to suit individual preferences. Theoretically, this should serve to improve automobile seat satisfaction and, consequently, the driving experience. Unfortunately, occupants may, in some ways, be overwhelmed by the many options. One of the potential consequences is discomfort. In this context, Hnatiw (1999) attempted to address the following question in one of his newspaper articles:

> "Our new car has a two position driver's seat memory. This is the first time I can have my 'own' driving position as opposed to a compromise between my husband and I. In the past I've never had time to fiddle with all of the controls and get it just right. With our new car, all I have to do is press a single button and my preferred position magically appears. How can I best set the memory for my own needs?"

This is a rather common question, even in vehicles not luxuriously equipped. The question will, as seats become more complex, continue to be asked by troubled consumers. Furthermore, the situation is expected to get worse before it gets better. Therefore, adjustability, in terms of many and varied features, may not be improving comfort (which is, after all, the intended purpose).

To improve automobile seat usage, the automotive seating industry needs to educate the occupant. In a 1986 study, Hosea et al. showed that many people have musculoskeletal problems attributable to the act of driving. Today, there are, undoubtedly, many more people who suffer from the same types of problems. By educating the occupant on how to use the seat to achieve a relaxed and effective driving position, one of the most significant issues related to back pain and general tiredness can be removed.

In the area of seat adjustability, it is immediately apparent that a disconnect exists between driver preferences and the available technology. The automotive seating industry should be better able to tell the driver how and in what order to adjust seat features to achieve a configuration that will maximize comfort. A review of the published literature on automotive seat comfort revealed a lack of information dealing with the technology-occupant interface.

Track position models are a notable exception. They have evolved over a period of more than 15 years. The current recommended practice for predicting population percentiles of driver selected track position is given by the Society of Automotive Engineers (1998).

Philippart et al. (1984) have also contributed to this field of research. They used regression equations to predict each of seven percentiles of the track position distribution using a second order function of seat height, obtained from empirical percentile values calculated for each of the vehicles in their database. Unfortunately, their work is restricted to the seven percentiles for which equations were developed.

Flannagan et al. (1996) created a more flexible model by adding the assumption that track position is normally distributed. They generated equations to predict the two parameters of the normal distribution (i.e., the mean and standard deviation). Means and standard deviations of track position were calculated for each of a number of vehicles. The means were regressed on driver population stature, seat height, steering wheel to ball of foot distance, cushion angle, and transmission type. The standard deviations were regressed on the percentage of males in the driver population (fit with a quadratic function). The adopted approach represented an important advancement because it allowed track position to be predicted for any target driver population.

More recent modeling efforts have started to question the assumption that track position can be described as a single normal distribution. The effort to improve prediction accuracy, particularly in the tails of the distribution, led to a new, fundamentally different approach to track position prediction. This new approach is the topic of Flannagan et al.'s (1998) latest paper.

The precision afforded by the latest models, while impressive, is for most applications unnecessary. The ultimate goal should be to provide the driver with a reasonable starting position for each adjustable feature (track position included). Researchers should, almost definitely, expect the driver to deviate from the recommended starting position either initially or over the course of an extended drive. The premise is that consumers would be more likely to be satisfied with their automobile seats if they were provided with more direction on how to take advantage of the features designed to enhance comfort.

2.5 Seat Interface Pressure as an Objective Indicator of Comfort

With the advancement of technology, several objective measures of seat comfort have evolved (Nagashima, 1991; Park and Kim, 1997; Sheridan et al., 1991). More specifically, the technology for assessing seat interface pressure exists, and has existed for some time. What is lacking is a scientific method. Once established seat interface pressure will almost certainly evolve into a standard objective measure of seat comfort. This research hopes to be ground-breaking in this regard.

2.5.1 System Components

The development of advanced sensing and evaluation techniques has made it possible to begin to understand the relationship between seating comfort and objective measurements of the occupant-seat interface (Reed et al., 1991). It is, however, interesting to note that this technology was originally intended for bio-medical applications such as dental occlusion analysis and the study of human gait (Czernik and Miszczak, 1991; Maness et al., 1987; Podoloff and Benjamin, 1991; Podoloff and Benjamin, 1989; Soderholm, 1989). Until very recently, this technology, as applied to the study of seat comfort, relied on discrete pressure sensors positioned at a limited number of locations between the occupant and the seat, along with other custom modifications to the seat itself. Today, the aforementioned sensing and evaluation techniques have evolved into thin, flexible tactile sensor arrays used to study the pressure distribution between larger portions of the seat-occupant interface.

The application of these techniques to the study of the seat-occupant interface has allowed information to be gathered that was previously unavailable. This can be attributed to the high density of sensing cells provided by a grid-based structure. The use of this technology allows a wide variety of experiments to be conducted, in real-time, without requiring modification to the seats under investigation. The remainder of this section discusses the manufacturer-specified use of these sensors in the context of automobile seat evaluation (Tekscan, Inc., 1998).

Thin, flexible sensor arrays are at the heart of the seating analysis system. The sensor, shown in Figure 2, features a grid-work of 48 columns and 44 rows based on 10 mm centers. At each of the 2112 intersection points on the grid, a sensing cell is created. An electrical resistance inversely proportional to the pressure applied relative to the cell's surface characterizes each sensing cell. By scanning the grid and measuring the electrical resistance at each grid point, the pressure distribution on the sensor's surface can be determined.

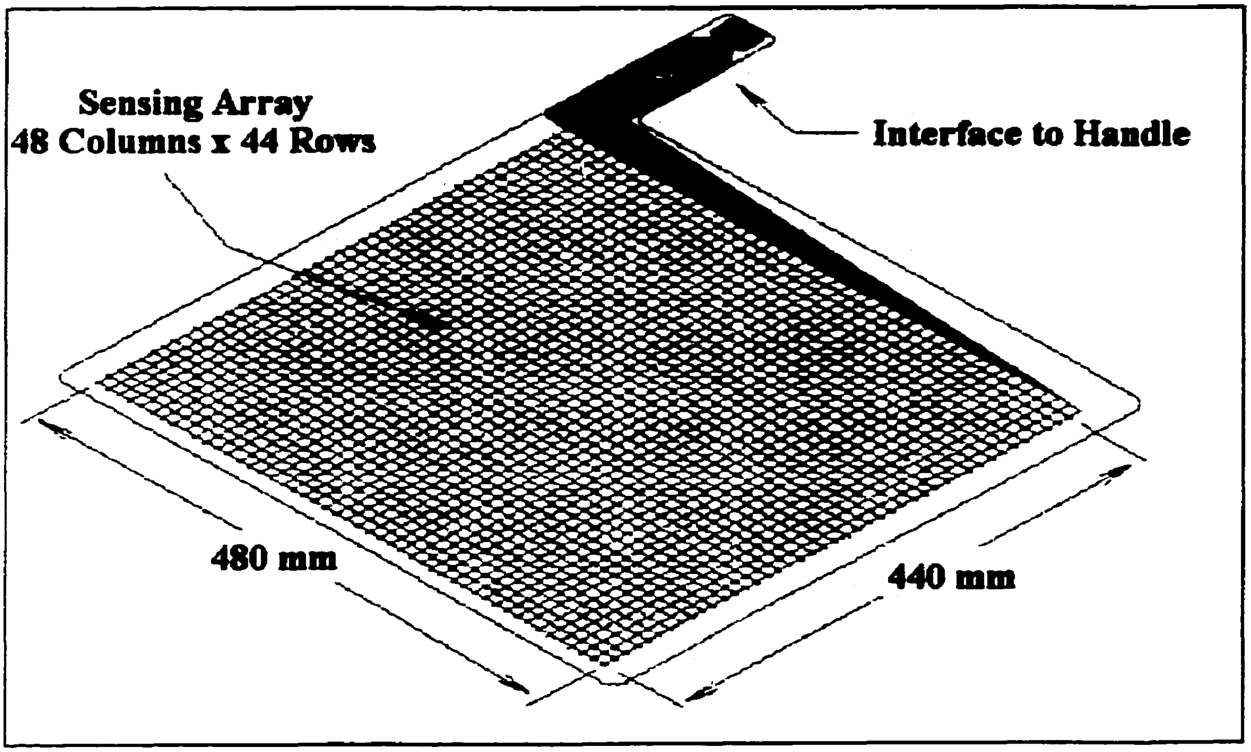


Figure 2: Sensor Array for Seating Analysis - A sensing cell is created at each intersection point in the grid [adopted from Podoloff (1993)].

The scanning electronics are packaged in a handle assembly (see Figure 3) that clips onto the sensor array's interface tab and provides the electrical connection to each sensing cell. The data acquired by the handle is then arranged into a serial data stream and "broadcast" via a thin cable to the "receiver" board (which is a ½ length PC bus expansion card). The receiver board then manages the flow of information between the handle and the computer's memory.

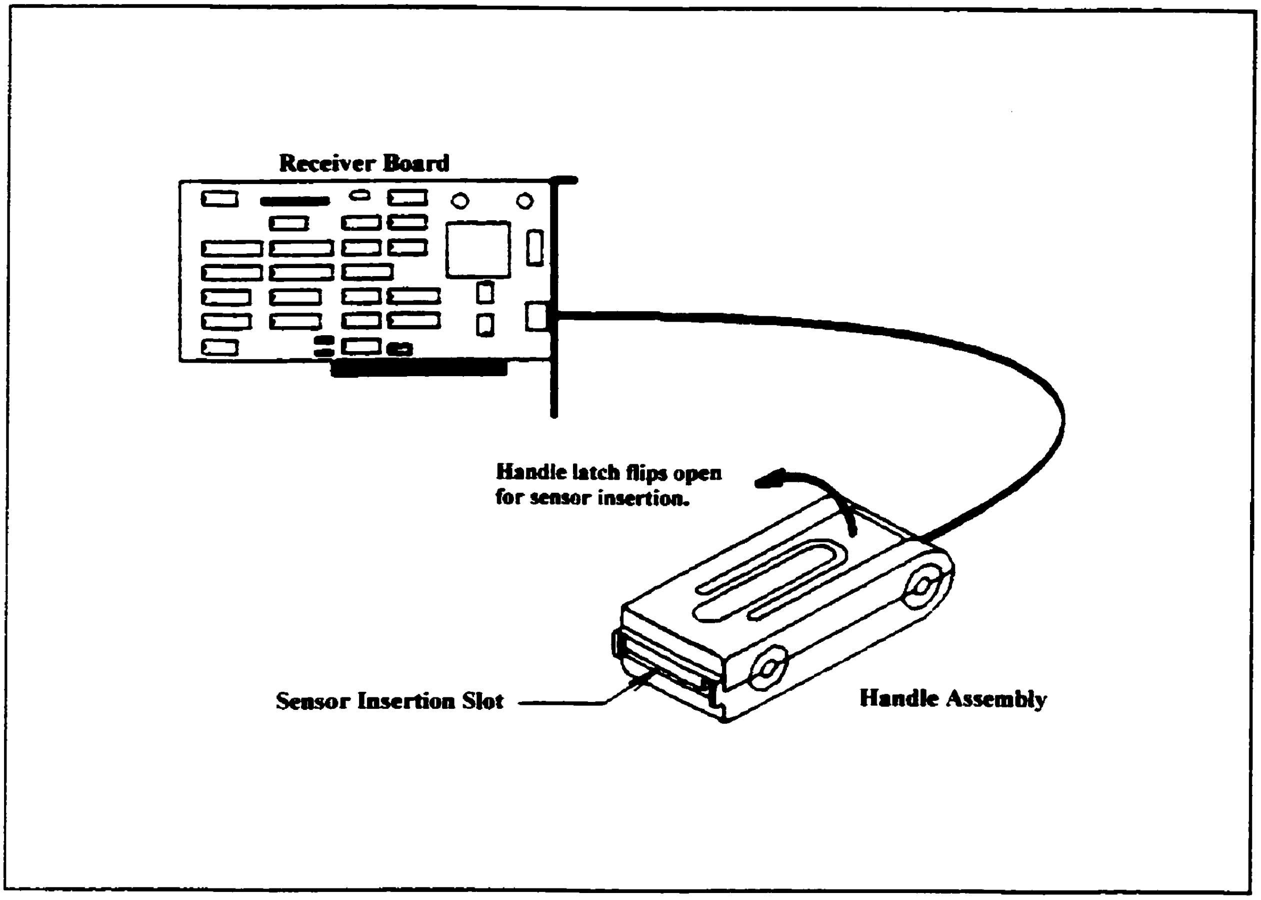


Figure 3: Acquisition Hardware for Reading Sensor Array Data [adopted from Podoloff (1993)]

The handle electronics feature a ratiometric, 8-bit A/D converter that compares the measured sensor resistance at each cell to a reference resistance. This ratio is then converted into a digital output value for the cell according to Equation 1.

$$D.O. = (R_f / R_s) * 255 \qquad \text{Equation 1}$$

Where:

D.O.	=	digital output volume
R_s	=	the resistance of the sensing cell
R_f	=	the reference resistance in the system handle (typically 20 K-Ohms)

The preceding equation results in an almost linear relationship between applied pressure and digital output. Therefore, by applying a known load to the sensor's surface while simultaneously monitoring the digital output, the calibration constants for the sensor can be determined. Calibration is the method by which the resistance for a given pressure applied to a specific cell is converted to a digital output [i.e., an actual unit of measure (i.e., g/cm^2)]. This conversion, for a typical sensing cell, is shown in Figure 4.

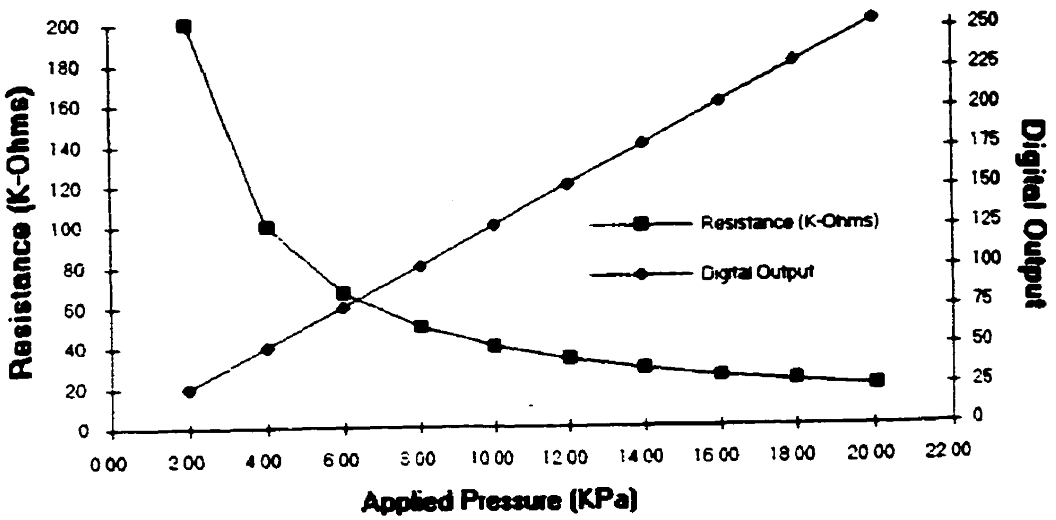


Figure 4: Seating Sensor Performance Specification [adopted from Podoloff (1993)]

The system software utilizes a mouse-controlled graphical user interface to manipulate windows of sensor data. The system is able to simultaneously display information from two sensor arrays in either a color-coded 2-D format or a wire-frame 3-D format. In addition to a real-time display capability, the system can record "force movies" of sensor information that can than be played back and analyzed. The user can select the data acquisition rate (up to a maximum of 100 Hz). The system advantages include data resolution, high-speed data collection, real time displays, and portability.

2.5.2 Guidelines for Interpretation of System Output

By attaching these thin, flexible mats to the seat cushion and seatback, information regarding pressure magnitudes and locations can be obtained both graphically and numerically. In recording and interpreting pressure distribution profiles, the following information should always be considered:

1. The applicability of body pressure distribution criteria is subject to vehicle packaging requirements or restrictions. That is, if H-Point is not met, the usefulness of seat interface pressure data are limited. All interior components are located from the H-Point. The H-Point (a) establishes the intended driving/riding position of each seat, (b) has X, Y, and Z coordinates relative to the designed vehicle structure, and (c) simulates the position of the pivot center of the human torso and thigh.

2. Good body pressure distribution should indicate sufficient and balanced support to body areas in contact with the seat.

3. Body pressure distribution should also meet the following specific requirements:

   - A good seat cushion will produce pressure distributions for occupants with a wide range of anthropometry that show peaks in the area of the ischial tuberosities with gradual decreases in pressure toward the front and sides of the cushion. In fact, Drummond et al. (1982) found that 18% of the occupant's body weight is taken up by each ischial tuberosity.

   - The pressure under the distal half of the thigh should be minimal. Akerblom (1948) was among the first to point out that the underside of the thigh has minimal resistance to deformation until the tissue nears its compression limit against the femur, leading to considerable restriction of circulation and consequent discomfort. Particular attention should be paid to the pressure distributions of small females, who are more likely to encounter interference from the front edge of the cushion. Figure 5 includes a typical seat cushion pressure distribution profile.

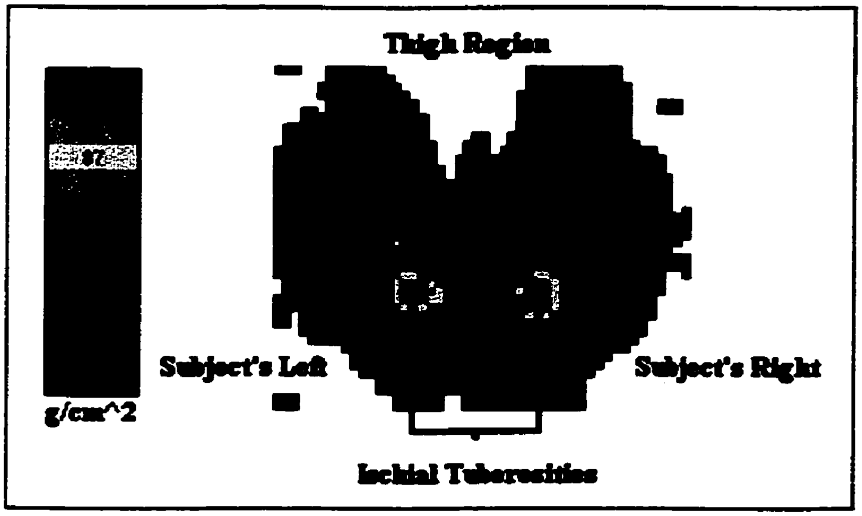


Figure 5: Typical Seat Cushion Pressure Distribution Profile

- With respect to the seatback, Kamijo et al., (1982) found higher lumbar pressure peaks in seats judged to be comfortable compared with lower values in uncomfortable seats. While a seatback with adequate lumbar support will produce pressure peaks in the lumbar area, excessively high pressure due to a very firm lumbar support can lead to discomfort in long-term sitting (Reed et al., 1991). Figure 6 presents a typical seatback pressure distribution profile.

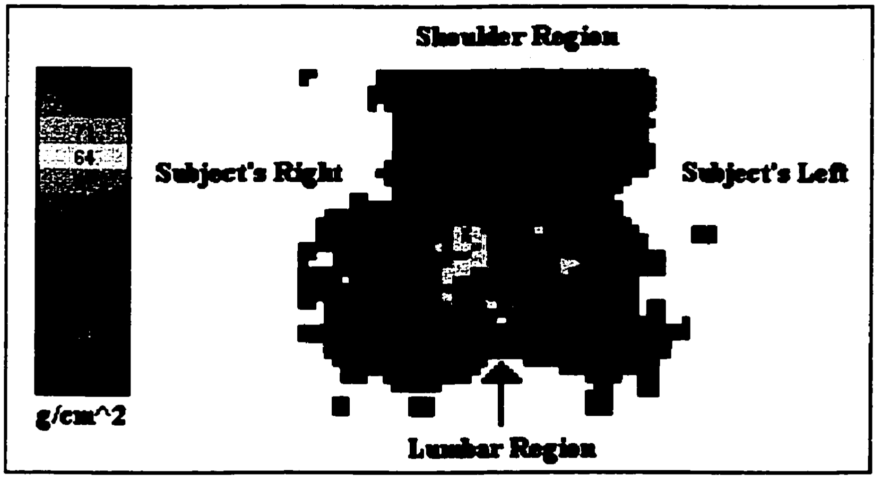


Figure 6: Typical Seatback Pressure Distribution Profile

- There should be no isolated high pressure points in contact regions other than the lumbar and ischial tuberosity regions. The physiological consequence of high pressure is an interruption in blood flow to the surrounding soft tissues (Bader et al., 1986 and Chow and Odell, 1978). This may cause discomfort.

- The use of excessive seat padding to reduce peak pressures by more evenly distributing pressure on the seat is likely to contribute to discomfort by restricting pressure relieving movement (Akerblom, 1948). The seat design should allow easy transitions to multiple postures. In this way, occupants can adjust their pressure distribution patterns with a simple shift in body position. If the seat is too soft, changing posture (within the constraints imposed by the driving task) will not substantially alter the pressure distribution profile.

- In addition to the parameters described above, Park and Kim (1997), note that the pressure in a comfortable seat cushion is distributed evenly and symmetrically around the ischial tuberosities. An asymmetrical seat cushion may compromise comfort. The same logic can be extended to apply to the seatback.

4. Pressure mapping test conditions should meet the following requirements:

   - The subject group should be representative of all anthropometric segments of the population. Seats are, theoretically designed to fit at least 90% of the population from small to large body sizes. A small female has some dimensions less than or equal to the 5th percentile. A large male, on the other hand, has some dimensions larger than or equal to the 95th percentile. The range between the small female and the large male approximates the adjustments needed in seating to accommodate anthropometric differences in body size. Body size is defined primarily by the distributions of standing height and body mass. Thus, distributions of standing height and body mass are considered to appropriately represent the anthropometric variation within the typical North American population (Reynolds, 1993).

   - The subject should be instructed to assume a driving posture.

Given the amount of information that is already known, it is safe to state that many researchers have, for some time, considered seat interface pressure as one of the most influential factors in seat comfort (Diebschlag et al., 1988; Hertzberg, 1972; Kamijo et al., 1982; Kohara and Sugi, 1972).

2.6 Seat Contour and Geometry

The seat contour and geometry, acting with the deflection characteristics of the cushion and seatback, control the position of the occupant. Well designed contouring supports the intended driving or riding posture and places all elements of the body at ease. Requirements for the overall geometry of the seat cushion and seatback are affected by the anthropometric characteristics of the seated occupant. Akerblom (1948) is widely credited with devising the principle that the seat should fit the sitter. This principle has since become the most universally employed concept in seating ergonomics. If a chair is to be used by only one sitter, careful measurements of that person's body will yield appropriate dimensional specifications for the seat. However, in the automotive seating industry, where a single seat must accommodate a variety of consumers, knowledge of population anthropometry is required.

A widely used design criterion is that the seat should accommodate the members of the population who lie between the 5th percentile female and 95th percentile male values on some anthropometric measure of interest. Note that it is not meaningful to refer to accommodating, for example, a 5th percentile female without specifying the anthropometric dimension that is being accommodated. Consider the fact that a woman who is 5th percentile female in standing height might have a thigh length that is shorter than 5th percentile. As a result she may experience uncomfortable pressure on the back of her knees from a seat cushion that is too long. In general, seat geometry and contour levels are specified by noting the constraining values among the set of 5th percentile female and 95th percentile male values for particular anthropometric dimensions.

2.6.1 Seat Cushion

In the case of cushion width, the 95th percentile female sitting hip breadth is used as a specification limit, since this measure exceeds the 95th percentile male sitting hip breadth. The case of cushion width is a good example of how seat geometry levels might appropriately be selected in practice. Using the principle of accommodation, the minimum cushion width would be chosen to be greater than the 95th percentile female sitting hip breadth of 432 mm (Anthropology Research Project, 1989). However, a larger minimum cushion width would be desirable, mainly because the cited anthropometric measurement does not include clothing. Since an automobile seat must generally be suitable for use in cold climates where heavy clothing is worn, a margin must be included for clothing thickness. Grandjean (1980) recommended a minimum cushion width of 480 mm, including clothing and an allowance for leg splay. Chaffin and Andersson (1991) cite recommendations from a variety of sources for office chair widths between 400 - 480 mm. Reed et al. (1994) believe that automobile seats should provide a clearance of 500 mm at the hips.

In terms of contour, it is logical to assume that the insert area of the cushion should remain relatively flat. If the contour is too barrel-shaped (like a canvas director's chair) there can be excessive pressure at the outer edges of the cushion leading to discomfort (known as hammocking). This claim needs to be substantiated with data.

Cushion length is an important determinant of comfort for several reasons. First, a cushion that is too long can put pressure on the back of the occupant's legs near the knee, an area that has many superficial nerves and blood vessels (Netter, 1989). Pressure in this area will lead to local discomfort and restricted blood flow to the legs (Reed et al., 1994). Second, a cushion that is too long will pull occupants forward, away from the seatback, eliminating the possibility of providing appropriate lumbar support. Third, a long cushion can restrict leg splay by interfering with knee movement, and may impede posture changes that alter pressure distribution under the buttocks and upper thigh.

Cushion length is constrained by the buttock-to-popliteal length of the 5th percentile female segment of the population. This dimension is measured on the seated occupant from the rearmost projection of the buttocks to the popliteal fold at the back of the knee. The Anthropolgy Research Project (1989) reported a 5th percentile female buttock-to-popliteal length of 440 mm. For general chair design, Chaffin and Andersson (1991) cite recommendations for cushion length, measured from the furthest forward contact point on the seatback to the front edge of the chair, of 330 - 470 mm. In the context of automotive seating and using the same definition of cushion length, Grandjean (1980) recommends 440 - 550 mm, while Keegan (1964) recommends 432 mm.

High cushion angles provide a cockpit feel whereas low cushion angles provide a more spacious feel. Recommendations should, therefore, be based on the requirements (i.e., customer expectations) of the vehicle segment for which the seat is being developed. Where possible, adjustable cushion angles are, obviously, preferred.

Cushion bolsters are ridge-like formations at the outboard edges of the cushion that are formed when the outboard surfaces are raised higher than the center surface. Once again, the cushion bolster height should be based on the customer expectations of the vehicle segment. Drivers of sport cars, for example, require more lateral support (as indicated by higher bolsters) than drivers of full size vans.

2.6.2 Seatback

Minimum seatback width at waist level is constrained by the large male segment of the population. Data from the Anthropology Research Project (1989) reveals that the 95^{th} percentile male seated waste height is 315 mm. The width of the seatback at waist height should, in practice, be larger to allow for posture changes and clothing. Schneider et al. (1985), based on 95^{th} percentile male upper back anthropometry, suggest a minimum upper seatback width of 456. As with most of the other recommendations cited in this section, a value larger than the minimum is desirable to allow for a range of postures and clothing.

Grandjean (1980) recommended 480 mm of seatback width. In the context of office chairs, Chaffin and Andersson (1991) recommend a seatback width between 360 and 400 mm. Office chairs are typically designed with narrower seatbacks to allow for greater upper torso mobility in a larger work envelope. In an automobile seat, a wider seatback provides more lateral stability during cornering.

Seatback width is integrally tied to the lateral contour of the seatback (i.e., seatback wings). Seatback wings are formed at the outboard edges of the seatback when the outboard surfaces are raised higher than the center surface. Reed et al. (1994) and Schneider et al. (1985) believe that the seatback wings behind the occupant's shoulders should be nearly flat to avoid interference with arm movement. The occupant should be able to extend his/her inboard arm straight to the side without interference from the seat. This recommendation was developed to accommodate small females.

Seatback height requirements are affected by geometric constraints imposed by Federal Motor Vehicle Safety Standards (U.S. Office of the Federal Register, 1992) dealing with head restraints for protection in rear impacts. Within these constraints there is only a small range of seatback heights that can be specified. From strictly anthropometric considerations, the seatback should be as high as possible without restricting rearward vision for small drivers. Grandjean (1980) recommends a 500 mm seatback height.

The seat contour in the lumbar area (middle of the lower back) will influence the shape of the spine. The most important characteristic of the seat contour in the lumbar region is that it should force the seated occupant's lumbar spine to assume the natural curvature (i.e. lordosis). As a generalization, lumbar comfort can be improved by providing adjustability (i.e., four-way adjustable mechanisms). When this is impractical, the contour of the seatback should be designed to provide some lumbar support. Reed et al. (1994) believe that the apex of the lumbar contour should be positioned between 105 - 155 mm above H-Point. The lack of standardization in measurement has, traditionally, made lumbar support prominence more difficult to specify (Reed et al., 1994).

3. METHOD

Each of the deliverables associated with the thesis had a specific set of objectives and a unique method. This section describes the systematic approach adopted to achieve the deliverables.

3.1 Automobile Seat Comfort Survey

Two specific aims guided the survey development portion of this research. The first was to demonstrate the reliability and validity of an automobile seat comfort survey developed using principles known to be associated with good survey design. The second objective was to present a method of data analysis that could be used to improve automobile seat design.

To begin, the controversy surrounding the appropriate statistical treatment of survey data was investigated in the context of two different front driver bucket seats evaluated as part of an extended duration ride & drive.

Then, using knowledge gained through the literature review, a unique seat comfort survey was developed to address (a) the wording of survey items, (b) the type and number of rating scale categories, (c) the verbal tags associated with the categories, and (d) the interest and motivation of the respondent. As part of this survey, occupants' perceptions regarding the aesthetic quality of the seat were gauged. This item was included to substantiate the claim that the appearance of a seat affects overall comfort ratings (Branton, 1969). Based on the survey, comfort indices were defined to eliminate the bias thought to plague overall seat comfort ratings. These indices are discussed, in more detail, later in this section.

Next, the survey was improved, in an iterative manner, through an examination of responses provided by 32 subjects evaluating three front driver bucket seats (each from a different vehicle manufacturer). Twelve subjects evaluated Seat #1. Seven subjects evaluated Seat #2. Thirteen subjects evaluated Seat #3. The seats, which were all cloth, had different seat features (eg., lumbar, cushion tilt) that allowed for varying amounts of adjustment. Prior to completing the survey, subjects were permitted to adjust all of the available seat features to attain a comfortable position. The same subjects evaluated the seats on two different occasions (Trial A and Trial B) approximately five months apart. The seat and the laboratory "set-up" were held constant. In order to hold the seats constant, they were purchased. This allowed for the seat to be evaluated, stored for five months in a controlled environment, and then reevaluated. Subjects were not aware of the fact that their responses were being used to assess the reliability and validity of the survey. In fact, most subjects did not remember sitting in the seat the first time. Even if they did, it would be unrealistic to expect them to recall their responses. The survey, while maintaining a high level of face validity, was improved using measures of test-retest reliability, internal consistency, criterion-related validity, and construct-related validity.

Finally, twelve subjects (six males and six females) evaluated five different front driver bucket seats using the reliable and valid survey. These five seats, which were different than those outlined above, were used as the basis for the remainder of this research. This case study was conducted in a repeated measures fashion. That is, the same 12 subjects evaluated all five seats. The seats were evaluated in the actual vehicles. The vehicles, each designed by a different manufacturer, were white with gray interior (1997 model year). The seats were selected to represent a range of good and bad seats (as defined by J.D. Power & Associates). Only seats from the compact car segment were selected. This decision was based on the assumption that seats from the same segment have comparable H-Point to Heel Point relationships (i.e., similar packages). The seats, which were evaluated approximately one month apart, were base level (i.e., cloth with manual track and recliner). The total track travel for each of the seats was 220 mm (Seat A), 225 mm (Seat B), 210 mm (Seat C), 230 mm (Seat D), and 240 mm (Seat E). Just as before, subjects adjusted the seat to a comfortable position prior to completing the survey. The results were used to demonstrate how the survey could be used to (a) compare different seats and (b) improve the design of the seat found to be least comfortable. The findings were also compared to the 1997 J.D. Power & Associates TGR (Things Gone Right) data from the compact car segment.

The survey was designed so that respondents who were satisfied with the comfort or support being assessed by a particular item would mark the "just right" box, which, in the ensuing analysis, corresponded to a score of zero. Most of the items could be rated from –3 to +3. To obtain a single score from the survey, the absolute deviation of each item from just right was summed. This score was considered an overall comfort index. A seatback comfort index could be obtained by computing the sum of the absolute deviation from just right for only those survey items related to the seatback. Similarly, the sum of the absolute deviation from just right for the survey items related to the cushion provided an index of cushion comfort. The seatback and cushion comfort indices are presented as an alternative means for seat system design teams to compare seat components. Of the three indices just described, the overall comfort index was most important to the defense of this thesis.

3.2 Scientific Method for Quantifying Automobile Seat Comfort

With the advancement of technology, several objective measures of seat comfort have evolved. Consumers, with their increased emphasis on comfort, are driving this technological advancement. Recognizing this, the automotive seating industry would like to quantify comfort in a manner that will allow for different seats to be distinguished. While the technology exists, a scientific approach to seat comfort data collection is lacking. The lack of an acceptable seat comfort evaluation method has hindered advances in the realm of seat comfort. One of the purposes of this research, while considering one available objective measure - seat interface pressure, was to pioneer the effort toward an acceptable seat comfort evaluation method.

Several pressure mat characteristics can influence the accuracy of the obtained measurements. These characteristics are controlled through calibration. When calibrating a sensor array, two points to consider are (a) how the forces or pressures are applied to the sensor and (b) whether or not the load is being applied uniformly over the contact area of the sensor array. These considerations are very important because the calibration of the sensor is only as good as the known conditions that were used to calibrate it. This research followed the calibration guidelines provided by Tekscan, Inc. (1998). These guidelines address conditioning, saturation, and load application.

While calibration addresses the uniformity and average nonlinearity of a pressure mat, many other sensor characteristics can influence the accuracy of the sensor measurements. This remainder of this section discusses some of these characteristics.

3.2.1 Repeatability

Repeatability is the ability of a device to respond in the same way to repeatedly applied stimulus. If, for example, pressure mats were to yield vastly different outputs under consistent test conditions, the confidence associated with the corresponding conclusions would suffer. Furthermore, it would be unrealistic to expect seat comfort researchers to use inconsistent measures for the purpose of prediction. In the context of this research, seat interface pressure method repeatability was assessed in a test-retest scenario. As part of the protocol, 17 subjects [mean standing height = 175.6 cm (STD = 8.7) and mean body mass = 74.6 kg (STD = 12.6)] were pressure mapped on two separate occasions. Four of the subjects were female. All 17 subjects participated in a test condition on day #1 and a retest condition on day #2. The pressure mapping procedure is described in more detail later in this section. The same seat and pressure mats were used on both days, although the pressure mats were re-calibrated at the start of the second day. The seat was equipped with a six-way power track (fore/aft, up/down for cushion front, and up/down for cushion rear), a power recliner, and a manual lumbar. It was valuable to use actual subjects as opposed to objects of fixed mass because, in the automotive seating industry, pressure distribution studies are typically conducted using real people. Subjects were, in both conditions, allowed to adjust any and all seat features. The pressure measures (described later in this chapter) were analyzed using a paired samples t-test.

3.2.2 Drift

Drift is the change in sensor (and system) output when a constant force is applied over a period of time. Among other things, the drift may be influenced by the sensor design, the sensor sensitivity, the interface material, the applied load, and environmental conditions. It is important to take drift into account when calibrating the pressure mat, so that it's effects can be minimized. The simplest way to accomplish this is to perform the pressure mat calibration in a time frame similar to that which will be used in the application. Due to the time frame used for this application (subjects sit for only a few minutes), drift was not expected to be a major issue.

3.2.3 Temperature Sensitivity

Sensor output will vary with temperature. To account for this, the sensors are calibrated at the temperature at which they will be used. This study was conducted in a temperature and humidity controlled environment. For this reason, temperature sensitivity is not expected to significantly affect the results.

3.2.4 Sensor Life / Durability

The actual life of a particular pressure mat depends on the application in which it is used. Under severe conditions, such as against hard surfaces, sharp edges, non-flat surfaces, sliding surfaces, or shear forces, a sensor may have a very limited life. In this study, due to the controlled environment and soft seat surface, durability was not compromised.

The seat interface pressure method, used for the repeatability analysis and the five-seat case study, was as follows:

1. Anthropometric measurements (i.e., standing height and body mass) were obtained for 12 subjects in a self-report fashion.

2. The pressure mats were, prior to each seat evaluation, calibrated according to the instructions outlined by Tekscan, Inc. (1998).

3. The seat cushion and seatback were fitted with the calibrated mats. These mats were securely attached to the seat using strips of masking tape. Care was exercised to ensure that the mats were placed in a consistent location (i.e., centered and tucked into the biteline) from subject-to-subject and seat-to-seat.

4. Subjects were not permitted to sit in the seat (on top of the mats) until they removed their wallets and belts. This was done to avoid false seat interface pressure readings.

5. Each subject was allowed to adjust the track position and the seatback angle. In the selected vehicle segment, as defined for this research, there were no other seat features to adjust. The preferred setting was called "driver selected seat position" or "comfort position".

6. Once set, the subject was pressure mapped.

7. The subject was asked to exit the seat so that the comfort position could be recorded. Track position was measured aft of heel point in estimated design position (the notion of estimated design position is discussed later in this chapter). Seatback angle was measured from vertical. The seatback angle was measured from the head restraint rod because the seatback frame could not be reliably accessed due to the trim cover and foam.

8. The mats were removed.

9. The subject was asked to re-enter the seat in order to complete the survey without interference from the mats. It should, at this point, be stated that some subjects completed the appearance rating item prior to sitting in the seat while others completed the item after exiting the seat. There was no standard procedure outlined for when subjects were to complete the appearance rating item. The reason should be obvious – it is difficult for subjects to rate the appearance of the seat if they are sitting in it.

10. In preparation for the next subject, the seat was returned to the estimated design position.

The entire procedure took approximately 30 minutes to complete (per subject). Each seat evaluation was completed within one day. There was a one-month delay between seat evaluations. Although the process was not truly randomized, subjects were not tested in any particular order (i.e., the order was definitely not consistent from seat-to-seat).

In the context of the case study, demographics and anthropometry were held constant by using the same 12 subjects for all five seats. The demographic and anthropometric data are included in Table 1. For clarification purposes, females were assigned a zero and males were assigned a one.

Table 1: Demographic and Anthropometric Characteristics of Subjects Evaluating Five Different Front Driver Bucket Seats using both Subjective and Objective Methods.

Subject	Gender	Standing Height (cm)	Body Mass (kg)
1	0	176	55
2	1	189	132
3	1	198	105
4	0	179	73
5	1	189	82
6	0	178	73
7	0	153	61
8	1	175	79
9	0	154	64
10	1	172	85
11	0	152	73
12	1	164	61
Mean		173	78
STD		15	21
Min		152	55
Max		198	132

The sample was considered representative of a typical North American population. Admittedly, the absence of good anthropometric data pertaining to civilian populations makes this claim questionable. This limitation is discussed in the conclusion chapter.

3.3 Driver Selected Seat Position

Many of today's seats come equipped with a tremendous amount of adjustability. Unfortunately, it is becoming apparent, based on various consumer reports, clinics, and trade magazines that intimidated or overwhelmed consumers do not know how to adjust the seat for maximum benefit and effect. One of the purposes of this research was to present preliminary information on recommended starting positions, in terms of seat adjustability, for occupants of different sizes. To this end, driver selected seat position information was recorded as part of the method described in section 3.2. Unfortunately, this information was collected for only three of the five seats (i.e., Seat A, Seat C, and Seat D).

3.4 Overall Comfort Model

In order to advance the notion that automobile seat comfort can be quantified, it was essential for this research to yield a predictive model linking the measured data (obtained through the scientific method presented in section 3.2) to the overall comfort index (dependent variable based on the reliable and valid survey). To accomplish this, the measured data was divided into a series of predictor variables. Eight of the predictor variables were related to seat interface pressure. They were:

- Cushion Contact Area (cm^2) - CCA
- Cushion Total Force (N) - CTF
- Cushion Load at the Center of Force (g/cm^2) - CCF
- Cushion Peak Pressure (g/cm^2) - CPP
- Seatback Contact Area (cm^2) - BCA
- Seatback Total Force (N) - BTF
- Seatback Load at the Center of Force (g/cm^2) - BCF
- Seatback Peak Pressure (g/cm^2) – BPP

Two additional predictor variables were anthropometric in nature. They were:

- Standing Height (cm) - HT
- Body Mass (kg) - WT

One variable was a demographic characteristic. It was:

- Gender (for modeling purposes, males were assigned a 1, while females were assigned a 0)

The final predictor variable was based on occupant's perception of seat appearance. It was:

- Appearance Rating [1 to 5 scale (5 is best)] - AR

3.5 Seat Contour and Geometry

To fairly compare the contour and geometry characteristics, the five seats needed to be similarly set-up. In the automotive seating industry, because seat designs vary, manufacturer specified design position is the standard way to compare seats. This information could not be obtained for the purposes of this research. As a consequence, a protocol was established to estimate each seat's design position. It was as follows:

1. The seatback angle was set to 25°. It was necessary to measure the seatback angle from the head restraint rod because the seatback frame could not be reliably accessed due to the foam and trim.
2. The track position was set to full-rear.
3. The H-Point machine, developed by the Society of Automotive Engineers (SAE) in 1962 (Society of Automotive Engineers, 1995) was placed in the seat (without weights). The H-Point machine is illustrated in Figure 7.

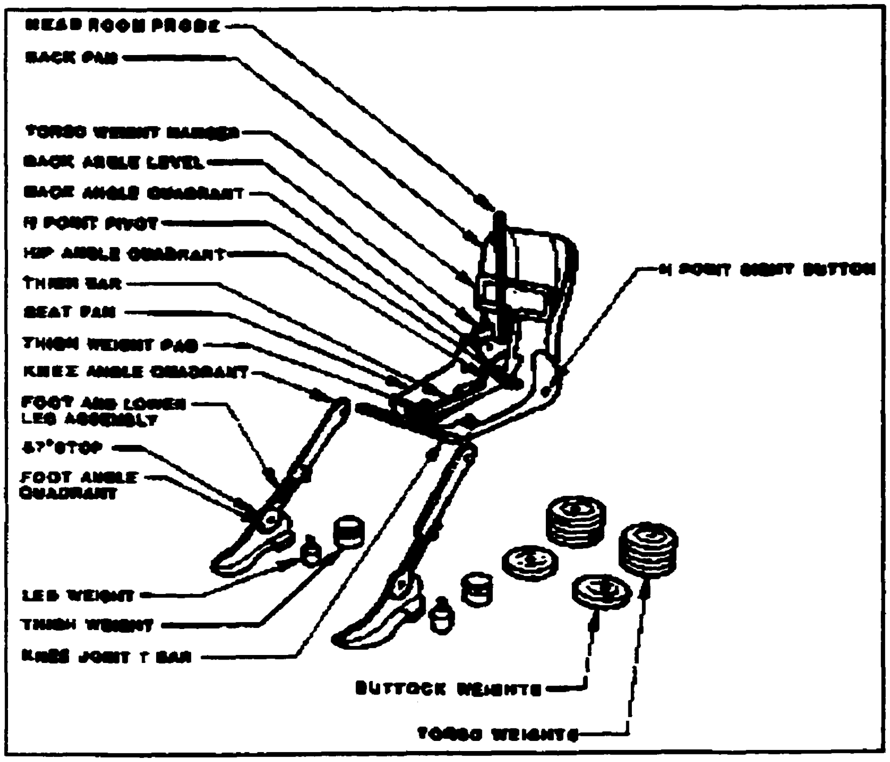


Figure 7: SAE H-Point Machine [adopted from the Society of Automotive Engineers (1995)]

4. The seat was adjusted until the H-Point machine's legs were adequately positioned in front of the pedals.

5. The H-Point machine was loaded (i.e., weights were added) according to the standard developed by the Society of Automotive Engineers (1995).

6. In this position, the H-Point to Heel Point relationships and the H-Point machine's critical angles (i.e., torso, hip, knee, and foot) were determined for each seat. Table 2 outlines this information and defines limits that can be considered representative of the compact car segment.

Table 2: Compact Car Limits for H-Point Machine Angles and H-Point to Heel Point Relationships

	Seat A	Seat B	Seat C	Seat D	Seat E	Mean	STD	Min	Max
Torso Angle (°)	24	24	24	23.5	24	23.9	0.2	23.5	24
Hip Angle (°)	96.1	98	96	95	97.3	96.5	1.2	95	97.3
Knee Angle (°)	129.8	131	127.5	127	128	128.7	1.7	127	128
Foot Angle (°)	87.9	85	87	89.5	87.5	87.4	1.6	85	87.5
H-Point to Heel Point - x (mm)	887	833	868	837	857	856.4	22.3	833	857
H-Point to Heel Point - z (mm)	223	246	222	169	243	220.6	30.9	169	243

Today, coordinate measuring machines (CMMs) are capable of measuring seat geometry and contour. In this context, the FaroArm (which is a multi-axis, portable CMM) is becoming more and more popular. This piece of equipment is shown in Figure 8.

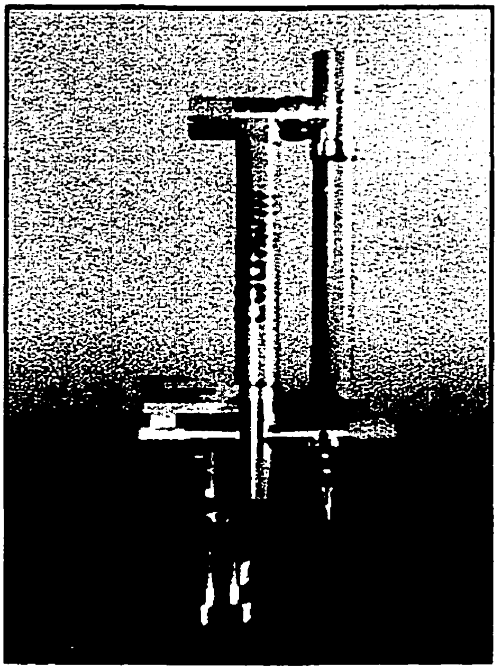


Figure 8: FaroArm used to Scan Automobile Seats

For this study, the FaroArm was used to digitize the spatial relationship between different seat components into an AutoCAD file (Autodesk, Inc., 1996). In addition to the contour, the H-Point (in estimated design position) was digitized. To perform this task, the SAE H-Point machine was placed in the seat. The H-Point was, as part of the analysis, related to the contour.

This investigation employed a Silver FaroArm with a 3.7 m spherical diameter. The arm weighed 7 kg and, according to the manufacturer, was accurate to within 0.180 mm. Reliability and accuracy are the primary advantages of the FaroArm.

Software known as AnthroCAM™ (Faro Technologies, Inc., 1998) interfaced with AutoCAD (Autodesk, Inc., 1996) and ran the FaroArm.

Prior to data acquisition, each vehicle was supported with the aid of four scissor jacks in order to isolate the suspension. Each jack was placed under the vehicle's frame (near each of the tires). The jacks were slowly cranked until resistance was encountered. At this point, each jack was cranked a little at a time until the vehicle did not deflect when loaded. The vehicle was then checked with a level against the side door frames and additional adjustments were made as needed. Next, the FaroArm was calibrated (per the manufacturer's instructions) by digitizing a 25 mm sphere. The calibration error, according to the manufacturer, must be less than .076 mm. If the calibration error was greater than this value, the procedure was repeated until an acceptable calibration value was obtained.

After setting the seat to the estimated design position (shown in Table 2), an alignment was created to establish a coordinate system (x, y, and z plane). An XZ plane was used to define the centerline of the seat and additional detail concerning trim construction (i.e., design sews). An XZ plane was created in the AutoCAD file (Autodesk, Inc., 1996) between the inboard and outboard edges of the seat. Two separate planes, one for the seatback and one for the cushion, defined the cross car sections. For each seat, the seatback plane was rotated to the estimated design position torso angle (refer to Table 2). The cushion plane was not rotated. The distance between cross sections was set to 50 mm, beginning from the H-Point (both for the cushion and seatback). The minimum distance between points was set to 0.1 mm. This, basically, served to filter through points and delete redundant data. As part of the actual scanning process, the probe was passed back and forth over the selected plane. Each time the probe passed over the plane a point was digitized. Once enough, data points were collected, AnthroCAM™ (Faro Technologies, Inc., 1998) was used to "connect the dots" in each of the specified planes.

Points were taken to the center of the probe. For this reason, the scan lines needed to be offset by the radius of the probe (i.e., 3 mm). Each scan line was offset individually. This was an AutoCAD function (Autodesk, Inc., 1996).

The finished scan, an example is shown in Figure 9, was then dimensioned. For this study, cushion width, cushion insert width, seatback width, and seatback insert width were measured tangent and parallel to the horizontal line passing through the point representing the seat centerline on the undeflected contour. Cushion bolster height and seatback wing height were measured from the highest point on the bolster/wing to the parallel line passing through the point representing the seat centerline on the undeflected contour. Since there are two bolsters/wings at each cross car section, the reported dimension was the average of the two measurements. With respect to the cushion, a total of six cross-car sections were digitized (i.e., in 50 mm increments from H-Point to +250 mm from H-Point). The seatback scan data consisted of eight cross car sections (i.e., in 50 mm increments from H-Point to +350 mm from H-Point). In automobile seat design, it is most useful to provide cushion length guidelines expressed from H-Point. For this reason, cushion length was operationally defined as the horizontal distance from H-Point to the nose of the cushion. Cushion angle was measured from horizontal. Seatback height, based on Federal Motor Vehicle Safety Standards (U.S. Office of the Federal Register, 1992), was measured as the vertical distance from the biteline to the top of the seatback (not considering the head restraint). The biteline is defined as the region where the cushion and seatback converge. The apex of the lumbar contour is defined as the most prominent point on the seatback contour tangent and parallel to the design position torso line. Once identified, a line is drawn through the apex that is perpendicular to the torso line. The height of the apex is measured from H-Point along the torso line to this line. Lumbar prominence, for the purposes of this thesis, is measured as the perpendicular distance from the identified apex to the torso line. The operational definitions of the seat dimensions are more clearly presented in Figure 10.

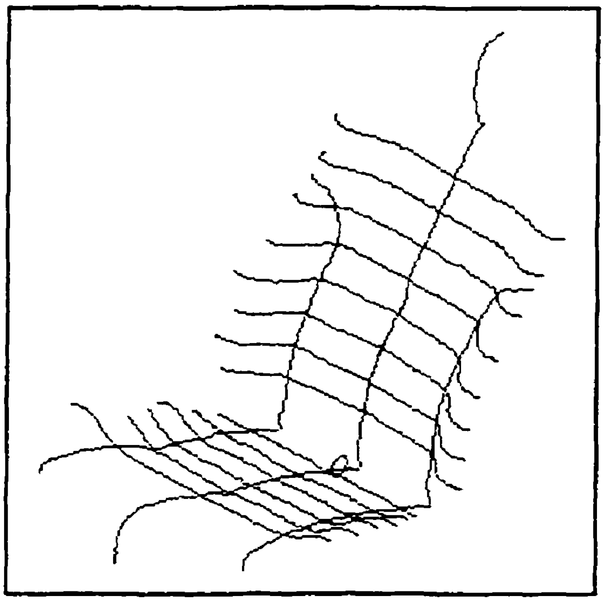


Figure 9: Sample Data Representing the Scanned Surface of an Automobile Seat

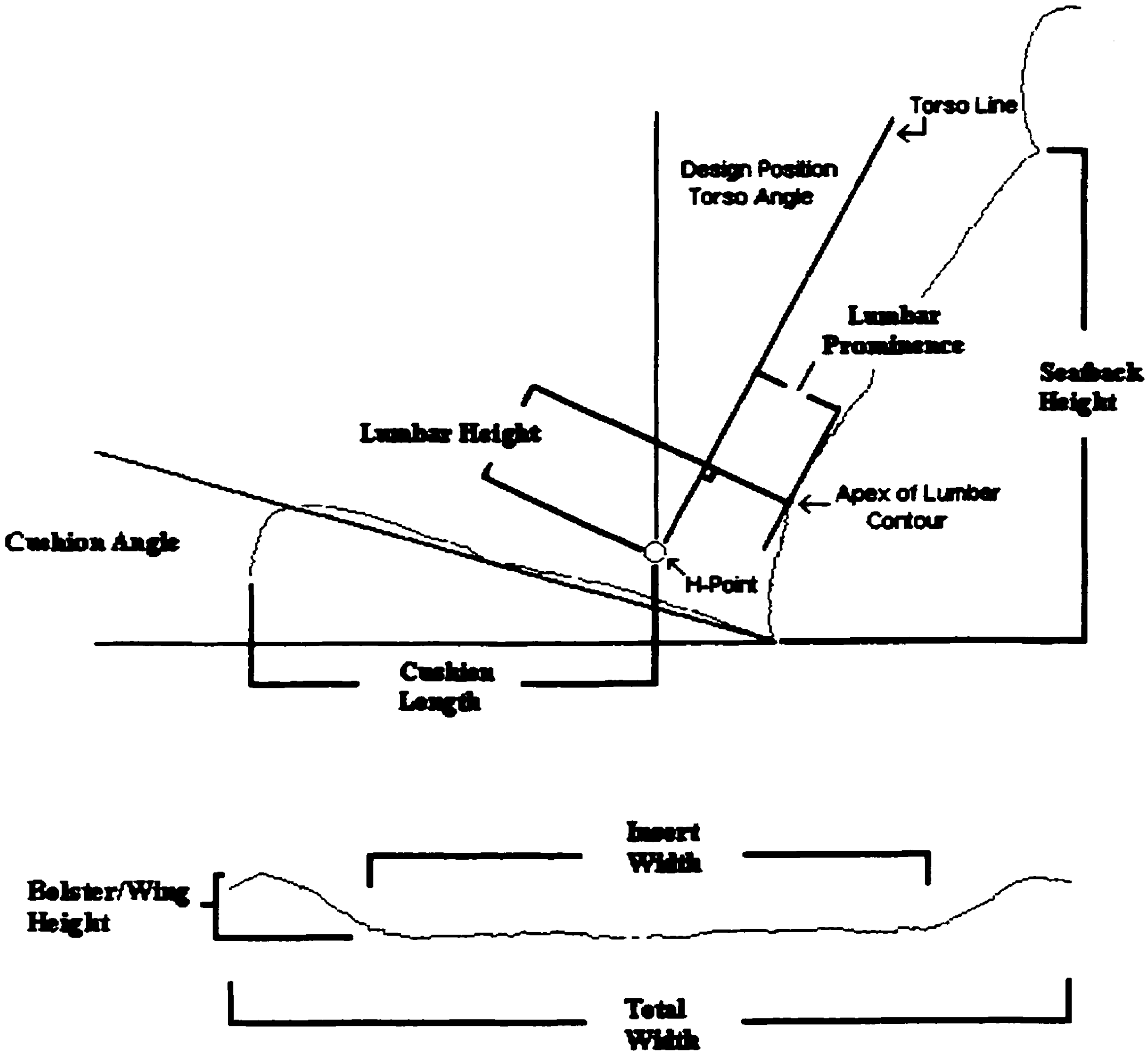


Figure 10: Operational Definitions of Dimensions Obtained From Scan Data

To help determine where the seats are different, centerline scans and cross-car sections were overlaid over H-Point. This information was used to derive contour and geometry recommendations. These recommendations should produce seat interface pressure characteristics that are perceived, by a wide range of the population, as comfortable.

4. RESULTS AND DISCUSSION

4.1 Automobile Seat Comfort Survey

Seat comfort, at the vehicle manufacturer level, is typically assessed over the course of a two -day ride & drive. Each ride & drive leg is two hours long. Participants are usually asked to provide feedback on a predetermined survey at various points during the ride & drive (e.g., 10-minute mark, one-hour mark, and two-hour mark). Due to the nature of the process, it is unrealistic to expect more than eight occupants to evaluate a single seating position over the course of two days. The data captured in Table 3 outlines respondent ratings of showroom comfort (10-minute mark), comfort at the one-hour mark, and long-term comfort (two-hour mark) for two different front driver seats (located in different vehicles). The rating scale ranged from 1 (poor) to 5 (world class). The same eight occupants evaluated both seats.

Table 3: Sample Survey Data from a Vehicle Manufacturer Sponsored Ride & Drive. The comfort score can range from one (poor) to 5 (world class).

	Showroom Comfort		Comfort After 1 Hour		Long-Term Comfort	
Subject	Seat A	Seat B	Seat A	Seat B	Seat A	Seat B
1	4.0	3.5	4.0	3.0	4.0	2.5
2	4.0	3.0	4.5	3.5	4.5	3.5
3	2.5	3.5	2.5	4.0	2.5	4.0
4	4.5	4.0	4.5	3.5	4.5	3.5
5	4.0	3.0	4.0	2.5	4.0	2.5
6	4.5	3.5	4.5	3.0	4.5	3.0
7	3.5	4.0	3.0	3.0	3.0	3.0
8	3.5	3.0	4.0	3.0	4.0	3.0
Average	3.8	3.4	3.9	3.2	3.9	3.1

Even with differences that are not as drastic as those outlined in Table 3, most seat system design teams would, early in the comfort development process, conclude that Seat A should be the target. Later in the comfort development process, the team may want to know why Seat B is not as comfortable as Seat A or how to make Seat B more like Seat A. Design changes are, ultimately, made based on this data. This is a flawed approach for two reasons. Firstly, as per the literature review section, there is debate as to whether parametric statistics can justifiably be applied to ordinal data. Computing means and then comparing them, as in this example, amounts to a parametric analysis. Secondly, without understanding whether the difference is statistically significant, it is impossible to state, based on the preceding data, that Seat A is more or less comfortable than Seat B.

It was felt that, in the context of automobile seat comfort, resolution to the controversy surrounding the statistical treatment of survey data was required. For this reason, the data in Table 3 (even though it is limited in terms of sample size) was analyzed using both non-parametric and parametric statistics.

Wilcoxon's Signed-Ranks Test is a nonparametric procedure used with two related data sets to test the hypothesis that the two data sets have the same distribution. It makes no assumption about the shapes of the distributions of the two data sets. This test takes into account information about the magnitude of differences within pairs and gives more weight to pairs that show large differences than to pairs that show small differences. The test statistic is based on the ranks of the absolute values of the differences between the two variables. A definition of Wilcoxon's Signed-Ranks Test was felt to be necessary because nonparametric statistics are, in general, not very popular in the automotive seating industry. The ranks are included in Table 4 and the test statistics are shown in Table 5.

Table 4: Ranks for Vehicle Manufacturer Sponsored Ride & Drive Data

		N	Mean Rank	Sum of Ranks
Showroom Comfort	Negative Ranks	6[a]	4.50	27.00
	Positive Ranks	2[b]	4.50	9.00
	Ties	0[c]		
	Total	8		
Comfort After 1 Hour	Negative Ranks	6[d]	3.67	22.00
	Positive Ranks	1[e]	6.00	6.00
	Ties	1[f]		
	Total	8		
Long Term Comfort	Negative Ranks	6[g]	3.75	22.50
	Positive Ranks	1[h]	5.50	5.50
	Ties	1[i]		
	Total	8		

a. Seat B < Seat A

b. Seat B > Seat A

c. Seat A = Seat B

d. Seat B < Seat A

e. Seat B > Seat A

f. Seat A = Seat B

g. Seat B < Seat A

h. Seat B > Seat A

i. Seat A = Seat B

Table 5: Wilcoxon's Signed-Ranks Test for Differences in Vehicle Manufacturer Sponsored Ride & Drive Data. The computation of this statistic amounts to a non-parametric analysis.

	Showroom Comfort	Comfort at 1Hour	Long Term Comfort
Z	-1.292[a]	-1.387[a]	-1.474[a]
Asymp. Sig. (2-tailed)	.196	.165	.140

a. Based on positive ranks.

Using a decision criterion of .05, the results imply that there is no difference between the two seats.

The data presented in Table 3, due to the manner in which it was collected, lends itself to a paired samples t-test. This is a commonly used parametric statistic. The results are shown in Table 6.

Table 6: Paired Samples t-Test for Differences in Vehicle Manufacturer Sponsored Ride & Drive Data. The computation of this statistic amounts to a parametric analysis.

	Paired Differences			95% Confidence Interval of the Difference				
Ride & Drive Data	Mean	STD	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Showroom Comfort Seat A - Seat B	0.375	0.744	0.263	-0.247	0.997	1.426	7	0.197
Comfort at 1 Hour Seat A - Seat B	0.688	0.998	0.353	-0.147	1.522	1.949	7	0.092
Long Term Comfort Seat A - Seat B	0.750	1.035	0.366	-0.115	1.615	2.049	7	0.080

Once again, using a decision criterion of .05, there is no difference between the seats. In other words, both the non-parametric and parametric approach yielded the same result. This finding in combination with the previously cited research (particularly the studies refuting Stevens' measurement classification theory) supports the contention that parametric statistics can be applied to ordinal data.

Table 7 presents a preliminary automobile seat comfort survey developed through careful consideration and special attention to the principles associated with good survey design and analysis (cited in Chapter 2).

Table 7: Preliminary Automobile Seat Comfort Survey

	Stop! Start Over	Poor, Major Improvements Needed	Fair, Minor Improvements Needed	Good, Slight Improvements Needed	World Class Seat
Overall Seat Appearance	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐

Item		**-3**	**-2**	**-1**	**Just Right**	**1**	**2**	**3**	
SEATBACK:									
1. Back Tailburn Pressure					☐	☐	☐	☐	too much
2. Location of Lumbar Support	too low	☐	☐	☐	☐	☐	☐	☐	too high
3. Amount of Lumbar Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
4. Lumbar Comfort	uncomfortable	☐	☐	☐	☐				
5. Amount of Mid-Back Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
6. Mid-Back Comfort	uncomfortable	☐	☐	☐	☐				
7. Amount of Shoulder Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
8. Seat Back Length	too short	☐	☐	☐	☐	☐	☐	☐	too long
9. Shoulder Comfort	uncomfortable	☐	☐	☐	☐				
10. Amount of Back Lateral Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
11. Back Lateral Comfort	uncomfortable	☐	☐	☐	☐				
12. Seat Back Feel / Firmness	too soft	☐	☐	☐	☐	☐	☐	☐	too firm
13. Overall Back Comfort	uncomfortable	☐	☐	☐	☐				
CUSHION:									
14. Cushion Tailbone Pressure					☐	☐	☐	☐	too much
15. Amount of Ischial / Buttocks Support	too little	☐	☐	☐	☐	☐	☐	☐	too high
16. Ischial / Buttocks Comfort	uncomfortable	☐	☐	☐	☐				too much
17. Amount of Thigh Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
18. Cushion Length	too short	☐	☐	☐	☐	☐	☐	☐	too long
19. Thigh Comfort	uncomfortable	☐	☐	☐	☐				
20. Amount of Cushion Lateral Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
21. Cushion Lateral Comfort	uncomfortable	☐	☐	☐	☐				
22. Cushion Feel / Firmness	too soft	☐	☐	☐	☐	☐	☐	☐	too firm
23. Overall Cushion Comfort	uncomfortable	☐	☐	☐	☐				
24. Overall Seat Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
25. Overall Seat Comfort	uncomfortable	☐	☐	☐	☐				

Recall that the comfort indices (seatback, cushion, and overall), obtained from this survey, were defined so that zero is just right. Therefore, the higher the score, the less comfortable the respondent. It is important to understand that while these measures (particularly the overall comfort index) are extremely important to the defense of this thesis they are, in some ways, limited. That is, the manner in which the comfort indices were defined does not, obviously, provide insight into the nature of the seat problem. They do, however, provide the seat system design team with gross measures of comfort that can be used to compare seats on a macro level. These indices are, probably, best suited to the benchmarking phase of development. An item-by-item analysis, because of its emphasis on particular regions of the seat, would, on the other hand, be more appropriate during program specific comfort development.

At this point, it is possible to use a parametric approach to assess the reliability and validity of the survey shown in Table 7. Recall that the data set was obtained by having 32 subjects complete the survey (on two separate occasions approximately five months apart) while sitting in one of three different seats. The raw survey data, as well as the anthropometric and demographic characteristics of the 32 subjects, are included in Appendix A.

To begin, it was essential to reduce the survey measures into two components: a true score component and a measurement error component. A reliable survey item contains little measurement error. It is, however, impossible to directly observe the true score and error components of an actual score on a survey item. Instead, correlation techniques are used to give an estimate of the extent to which the survey item reflects true score rather than measurement error. Simply put, the concept of reliability refers to the extent that a survey is relatively free of random error and is consistent in the numbers assigned to the various survey items. There are several ways of estimating reliability; each involves computation of a correlation coefficient.

Test-retest reliability measures the same individuals at two points in time. A correlation coefficient is calculated to determine the relationship between the test score and the retest score. High reliability is indicated by a high correlation coefficient. For the purposes of this investigation, survey items will be accepted as reliable if the correlation coefficient is statistically significant. Due to its focus on variations over time, the test-retest estimate is often called the coefficient of stability. The test-retest reliability results (per survey item) are included in Table 8 (Trial A vs. Trial B).

Table 8: Test-Retest Reliability of Ratings obtained from the Preliminary Automobile Seat Comfort Survey presented in Table 7

Item	r	p	N
Appearance Rating	0.785*	0.000	29
Seatback-Specific Items:			
1. Back Tailburn Pressure	0.327	0.068	32
2. Location of Lumbar Support	-0.186	0.308	32
3. Amount of Lumbar Support	0.817*	0.000	31
4. Lumbar Comfort	0.604*	0.000	32
5. Amount of Mid-Back Support	0.402*	0.023	32
6. Mid-Back Comfort	0.451*	0.010	32
7. Amount of Shoulder Support	0.228	0.210	32
8. Seat Back Length	0.244	0.179	32
9. Shoulder Comfort	0.127	0.490	32
10. Amount of Back Lateral Support	0.641*	0.000	32
11. Back Lateral Comfort	0.421*	0.017	32
12. Seat Back Feel / Firmness	0.556*	0.001	31
Seatback Comfort Index	0.646*	0.000	32
13. Overall Back Comfort	0.581*	0.001	31
Cushion-Specific Items:			
14. Cushion Tailbone Pressure	0.184	0.314	32
15. Amount of Ischial / Buttocks Support	0.336	0.060	32
16. Ischial / Buttocks Comfort	0.637*	0.000	32
17. Amount of Thigh Support	0.703*	0.000	32
18. Cushion Length	0.590*	0.000	32
19. Thigh Comfort	0.610*	0.000	32
20. Amount of Cushion Lateral Support	0.205	0.269	31
21. Cushion Lateral Comfort	0.496*	0.004	32
22. Cushion Feel / Firmness	0.548*	0.001	32
Cushion Comfort Index	0.576*	0.001	32
23. Overall Cushion Comfort	0.501*	0.003	32
Overall Items:			
24. Overall Seat Support	0.302	0.105	30
Overall Comfort Index	0.822*	0.000	32
25. Overall Seat Comfort	0.517*	0.002	32

*Correlation is significant at the 0.05 level.

Notice that there are three line items, shown in Table 8, which are not part of the preliminary survey, shown in Table 7. These are the aforementioned comfort indices. It should also be noted that there was some missing data. That is, N does not equal 32 for all pairs of data. This is due to the fact that subjects either omitted an item or inappropriately responded to the item (e.g., checked two boxes). These errors may have been related to the length of the survey. In other words, survey length may have compromised subject interest.

Sixteen of the original survey items (shown in Table 8) had statistically significant test-retest reliability. The overall indices were also shown to be statistically reliable. In fact, they were more reliable than the survey items to which they were meant to correspond [i.e., Item #13 (overall seatback comfort), Item #23 (overall cushion comfort), and Item #25 (overall comfort), respectively]. The implication is that there is less bias associated with the defined indices than with the individual items designed to assess overall comfort. More specifically, summing the items related to the seat component (i.e., seatback, cushion, or complete seat), assuming that the items are valid, eliminates, or at least reduces, the possibility of peripheral factors (e.g., vehicle nameplate, vehicle sticker price, etc.) biasing the rating. Table 9 reveals that the indices and the corresponding survey items are statistically related (in both Trial A and Trial B).

Table 9: Correlation between Overall Comfort Indices and Responses on Corresponding Items from the Preliminary Automobile Seat Comfort Survey presented in Table 7

Comparison	r	p	N
Trial A:			
Overall Back Comfort (Item #13) vs Seatback Comfort Index	-0.544*	0.002	31
Overall Cushion Comfort (Item #23) vs Cushion Comfort Index	-0.734*	0.000	32
Overall Seat Comfort (Item #25) vs Overall Comfort Index	-0.512*	0.003	32
Trial B:			
Overall Back Comfort (Item #13) vs Seatback Comfort Index	-0.616*	0.000	31
Overall Cushion Comfort (Item #23) vs Cushion Comfort Index	-0.576*	0.001	32
Overall Seat Comfort (Item #25) vs Overall Comfort Index	-0.423*	0.016	32

*Correlation is significant at the 0.05 level.

For this reason, Item #13, Item #23, and Item #25 can be replaced with the comfort indices (which yield the same information).

Based on the preceding analysis, the survey can be improved by eliminating the unreliable items and the items that presented redundant information. The net effect is a reduction in survey length. This should improve respondent interest and motivation. As a result, the quality of responses should increase. Revision #1 of the improved survey is shown in Table 10. Notice that the survey items are lettered in Table 10. Contrast this with the survey items in Table 7, which are numbered. The purpose was to distinguish between the surveys.

Table 10: First Revision of the Automobile Seat Comfort Survey

	Stop! Start Over	Poor, Major Improvements Needed	Fair, Minor Improvements Needed	Good, Slight Improvements Needed	World Class Seat
Overall Seat Appearance	**1**	**2**	**3**	**4**	**5**
	❑	❑	❑	❑	❑

Item		**-3**	**-2**	**-1**	**Just Right**	**1**	**2**	**3**	
SEATBACK:									
A. Amount of Lumbar Support	too little	❑	❑	❑	❑	❑	❑	❑	too much
B. Lumbar Comfort	uncomfortable	❑	❑	❑	❑				
C. Amount of Mid-Back Support	too little	❑	❑	❑	❑	❑	❑	❑	too much
D. Mid-Back Comfort	uncomfortable	❑	❑	❑	❑				
E. Amount of Back Lateral Support	too little	❑	❑	❑	❑	❑	❑	❑	too much
F. Back Lateral Comfort	uncomfortable	❑	❑	❑	❑				
G. Seat Back Feel / Firmness	too soft	❑	❑	❑	❑	❑	❑	❑	too firm
CUSHION:									
H. Ischial / Buttocks Comfort	uncomfortable	❑	❑	❑	❑				too much
I. Amount of Thigh Support	too little	❑	❑	❑	❑	❑	❑	❑	too much
J. Cushion Length	too short	❑	❑	❑	❑	❑	❑	❑	too long
K. Thigh Comfort	uncomfortable	❑	❑	❑	❑				
L. Cushion Lateral Comfort	uncomfortable	❑	❑	❑	❑				
M. Cushion Feel / Firmness	too soft	❑	❑	❑	❑	❑	❑	❑	too firm

Another approach to assessing reliability is to examine the internal consistency of the survey. Seat comfort surveys typically consist of several items that are combined on the assumption that the values yielded across items are consistent. The survey included in Table 10 is no different. One source of error is that associated with the particular items that make up a survey. Because of the way it is worded, or how hard it is, or what exact knowledge it requires, an item may or may not represent the same domain as others designed to measure the same thing. The internal consistency index estimates the extent to which the various items all measure the same thing (in this case, seat comfort). It is essentially the combined (average) correlation of scores on every item with every other item in the measure. The formula for estimating internal consistency is:

$$R_{xx} = k * r_{ij} / 1 + (k - 1) * r_{ij} \qquad \text{Equation 2}$$

where k is the number of items and r_{ij} is the average intercorrelation among items. The notion of internal consistency, as outlined in this section, is beginning to sound a little like validity (to be discussed later in this section).

The intercorrelations among all 13 items (A through M) are shown in Table 11 (only Trial A). The average correlation coefficient was 0.0452. The total number of items is 78. Using Equation 2, the internal consistency index is 0.787. For this reason, the survey can be considered internally reliable.

Table 11: Intercorrelations between Items from the First Revision of the Automobile Seat Comfort Survey presented in Table 10

		A	B	C	D	E	F	G	H	I	J	K	L	M
Pearson Correlation	A	1,000	-,366*	-,072	-,205	,125	-,222	,480**	-,336	,014	-,105	-,382*	-,121	,228
	B	-,366*	1,000	-,104	,351*	,146	,373*	-,332	,152	,035	,000	,260	,531**	-,180
	C	-,072	-,104	1,000	,180	-,149	,251	,091	-,015	,365*	-,072	-,070	,005	,034
	D	-,205	,351*	,180	1,000	,169	,502**	-,119	,295	,095	-,204	,225	,352*	,064
	E	,125	,146	-,149	,169	1,000	,085	-,167	,069	-,227	-,079	,185	,299	-,202
	F	-,222	,373*	,251	,502**	,085	1,000	-,151	,012	-,008	,130	,401*	,421*	-,154
	G	,480**	-,332	,091	-,119	-,167	-,151	1,000	-,403*	,102	,092	-,252	-,038	,635**
	H	-,336	,152	-,015	,295	,069	,012	-,403*	1,000	,002	-,297	-,162	-,007	-,049
	I	,014	,035	,365*	,095	-,227	-,008	,102	,002	1,000	,234	-,346	,191	-,071
	J	-,105	,000	-,072	-,204	-,079	,130	,092	-,297	,234	1,000	,398*	,137	,053
	K	-,382*	,260	-,070	,225	,185	,401*	-,252	-,162	-,346	,398*	1,000	,269	-,082
	L	-,121	,531**	,005	,352*	,299	,421*	-,038	-,007	,191	,137	,269	1,000	,087
	M	,228	-,180	,034	,064	-,202	-,154	,635**	-,049	-,071	,053	-,082	,087	1,000
Sig. (2-tailed)	A	.	,043	,702	,267	,504	,231	,007	,065	,939	,574	,034	,516	,218
	B	,043	.	,570	,049	,427	,035	,068	,406	,848	1,000	,150	,002	,325
	C	,702	,570	.	,323	,417	,166	,626	,933	,040	,694	,703	,980	,854
	D	,267	,049	,323	.	,356	,003	,522	,101	,606	,263	,216	,048	,729
	E	,504	,427	,417	,356	.	,644	,368	,707	,211	,666	,311	,096	,268
	F	,231	,035	,166	,003	,644	.	,417	,949	,964	,480	,023	,017	,401
	G	,007	,068	,626	,522	,368	,417	.	,025	,585	,622	,171	,839	,000
	H	,065	,406	,933	,101	,707	,949	,025	.	,990	,099	,376	,971	,788
	I	,939	,848	,040	,606	,211	,964	,585	,990	.	,198	,053	,294	,699
	J	,574	1,000	,694	,263	,666	,480	,622	,099	,198	.	,024	,455	,771
	K	,034	,150	,703	,216	,311	,023	,171	,376	,053	,024	.	,136	,656
	L	,516	,002	,980	,048	,096	,017	,839	,971	,294	,455	,136	.	,634
	M	,218	,325	,854	,729	,268	,401	,000	,788	,699	,771	,656	,634	.
N	A	31	31	31	31	31	31	30	31	31	31	31	31	31
	B	31	32	32	32	32	32	31	32	32	32	32	32	32
	C	31	32	32	32	32	32	31	32	32	32	32	32	32
	D	31	32	32	32	32	32	31	32	32	32	32	32	32
	E	31	32	32	32	32	32	31	32	32	32	32	32	32
	F	31	32	32	32	32	32	31	32	32	32	32	32	32
	G	30	31	31	31	31	31	31	31	31	31	31	31	31
	H	31	32	32	32	32	32	31	32	32	32	32	32	32
	I	31	32	32	32	32	32	31	32	32	32	32	32	32
	J	31	32	32	32	32	32	31	32	32	32	32	32	32
	K	31	32	32	32	32	32	31	32	32	32	32	32	32
	L	31	32	32	32	32	32	31	32	32	32	32	32	32
	M	31	32	32	32	32	32	31	32	32	32	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The validity of a survey refers to whether the number/score obtained from the survey/item truly reflects what the researcher intended to measure. In other words, if the goal is to measure automobile seat comfort with a series of questions, do these questions really tap automobile seat comfort? Reliability and validity are different yet related concepts. A reliable measure provides consistent readings but is not necessarily valid. On the other hand, a measurement is unlikely to be valid unless it is also reliable. In general, reliability is a necessary but not sufficient condition for validity, with reliability setting the upper bound to the level of validity that one can expect to find in a measure.

Estimating the validity of a survey can be done in various ways. Criterion-related validity is, in many respects, the most practically significant estimate of validity. It invokes the bottom line question of how much proven capability the instrument has in forecasting some criterion measure, such as automobile seat comfort. This type of validity is based on the premise that constructs are measured for a purpose: to improve forecasting ability. Thus, the most common index of criterion-related validity is the validity coefficient, the correlation of predictor x with criterion y (or r_{xy}). To assess this type of validity, a correlation coefficient was calculated between each item in revision level #1 of the survey and the overall comfort index (for Trial A).

The differences in rating scales made it imperative to consider scatter plots (shown in Figure 11 to Figure 24) prior to making a decision regarding criterion-related validity. Item A, C, E, G, I, J, and M (Figure 12, 14, 16, 18, 20, 21, and 24, respectively) could be rated from –3 to +3. Since zero represents just right, the relationship with the overall comfort index is expected to be parabolic. For these items, it was, therefore, appropriate to attempt to fit a quadratic model. It would be incorrect to conclude that one of these items is unrelated to the overall comfort index using a linear model. Linear models were, however, appropriate for Item B, D, F, H, K, and L (Figure 13, 15, 17, 19, 22, and 23, respectively). These are the items that were rated from zero to –3. The criterion-related validity results are shown in Table 12.

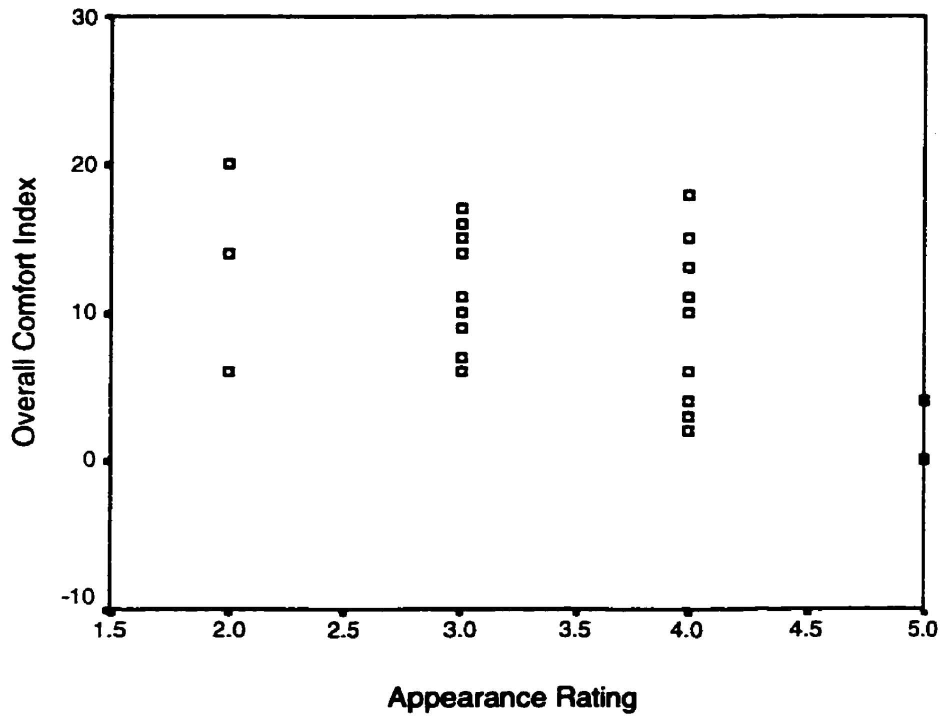


Figure 11: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Appearance Rating)

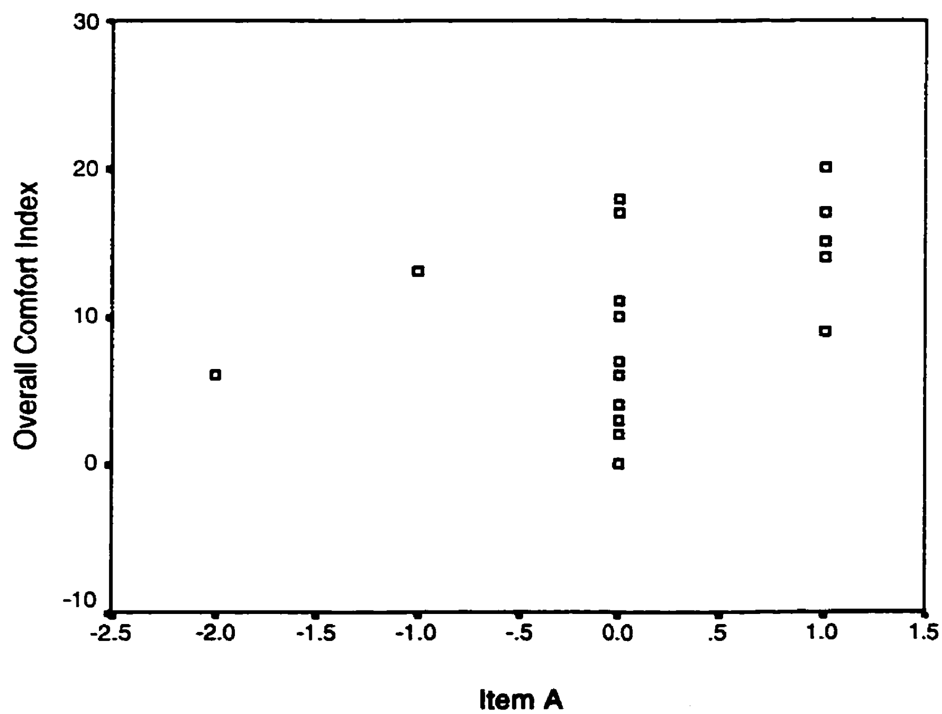


Figure 12: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item A)

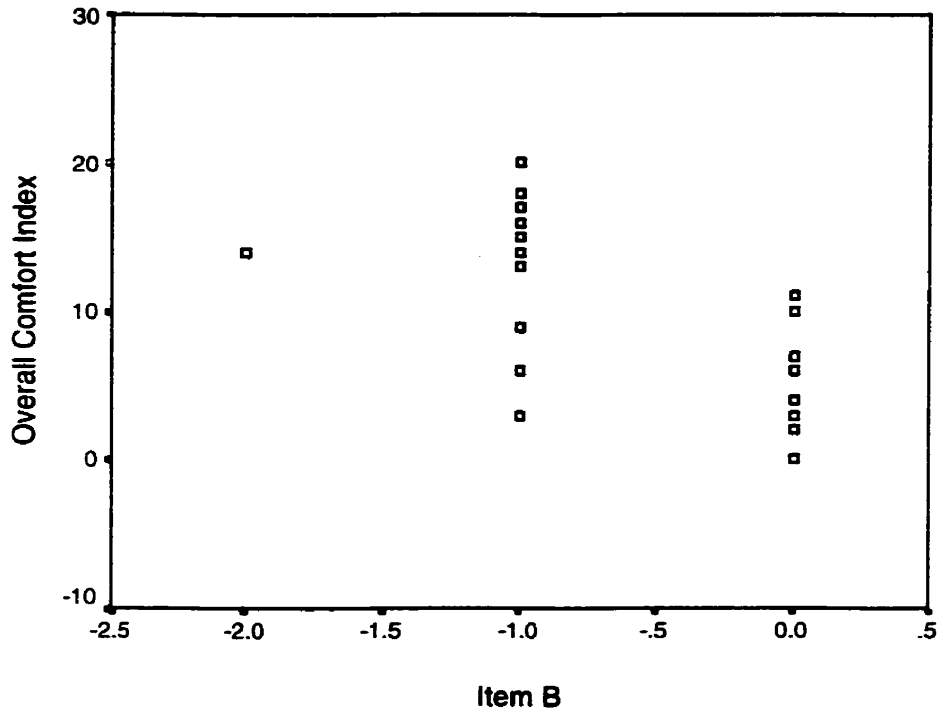


Figure 13: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item B)

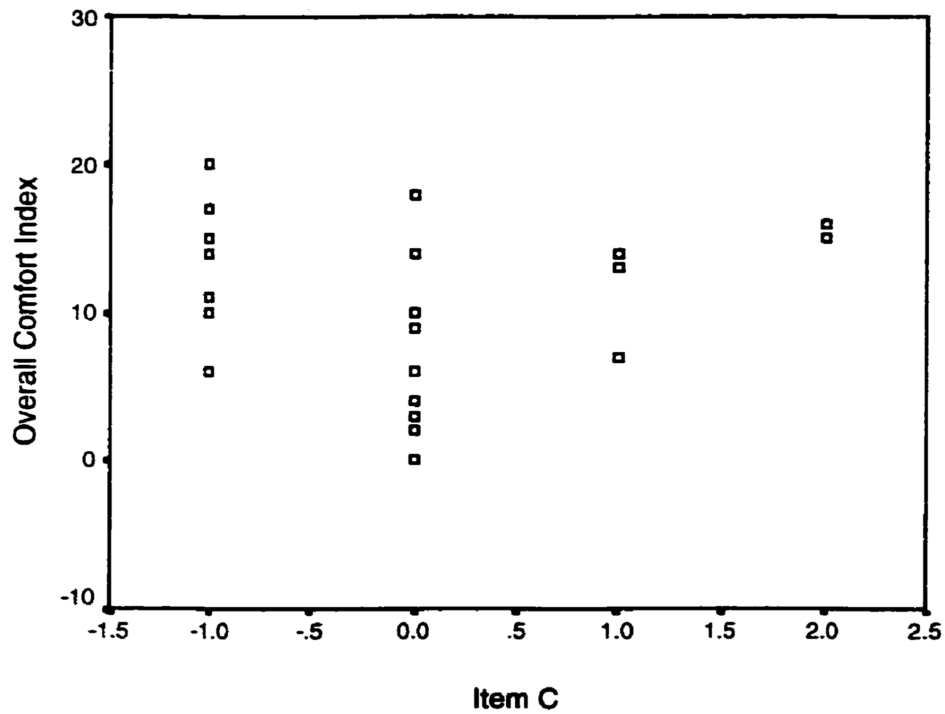


Figure 14: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item C)

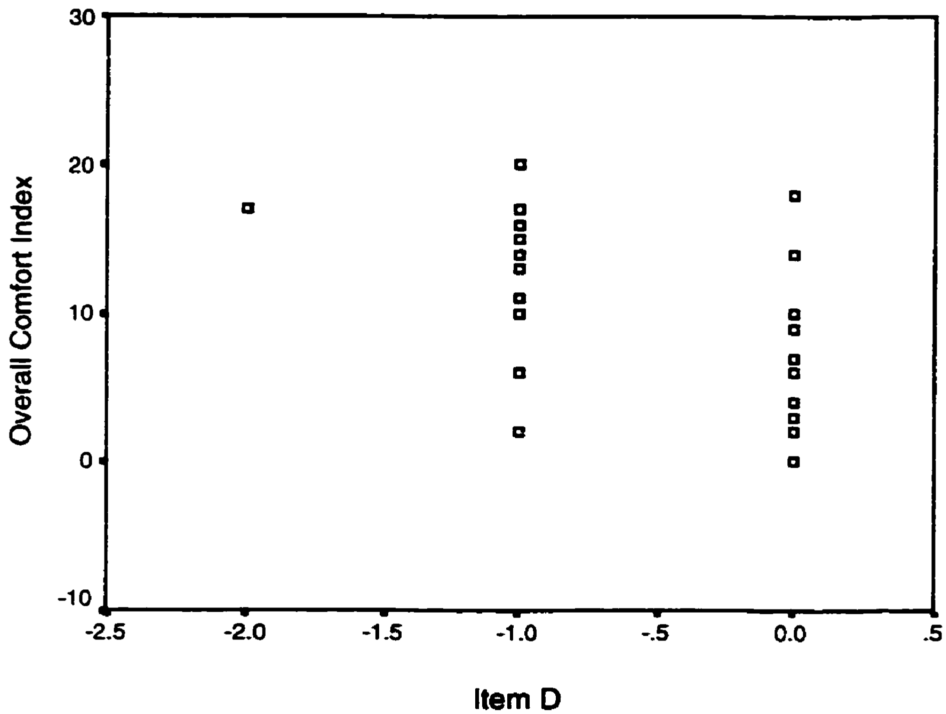


Figure 15: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item D)

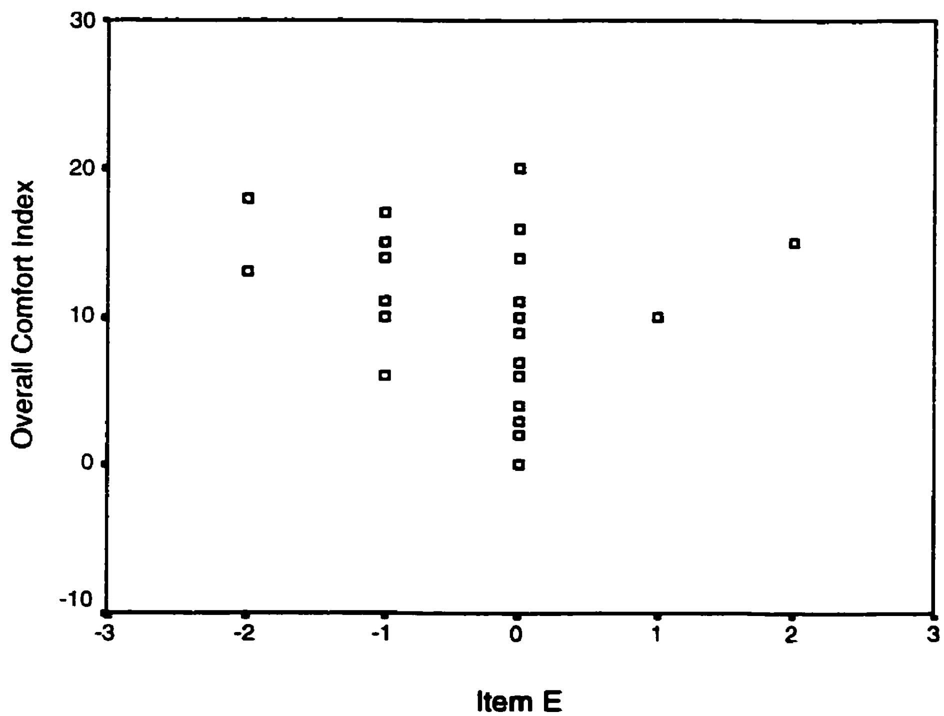


Figure 16: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item E)

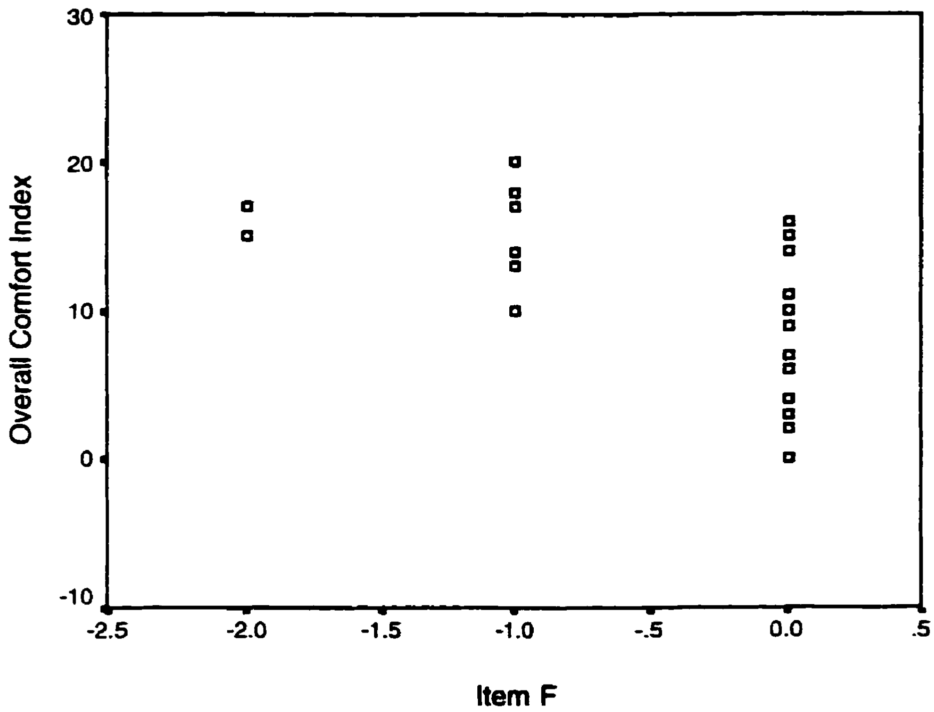


Figure 17: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item F)

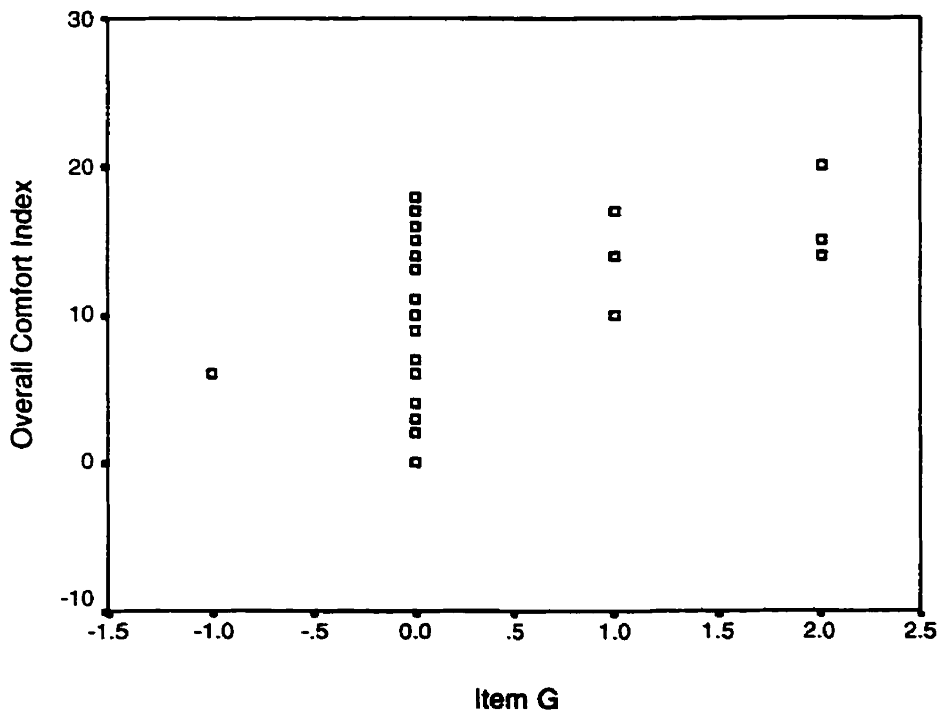


Figure 18: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item G)

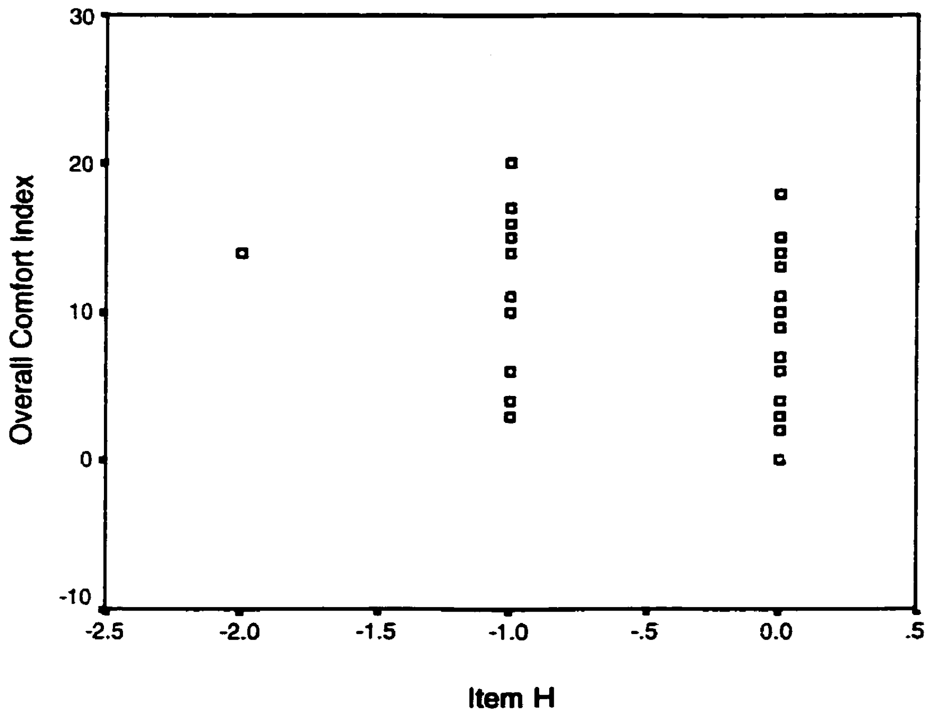


Figure 19: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item H)

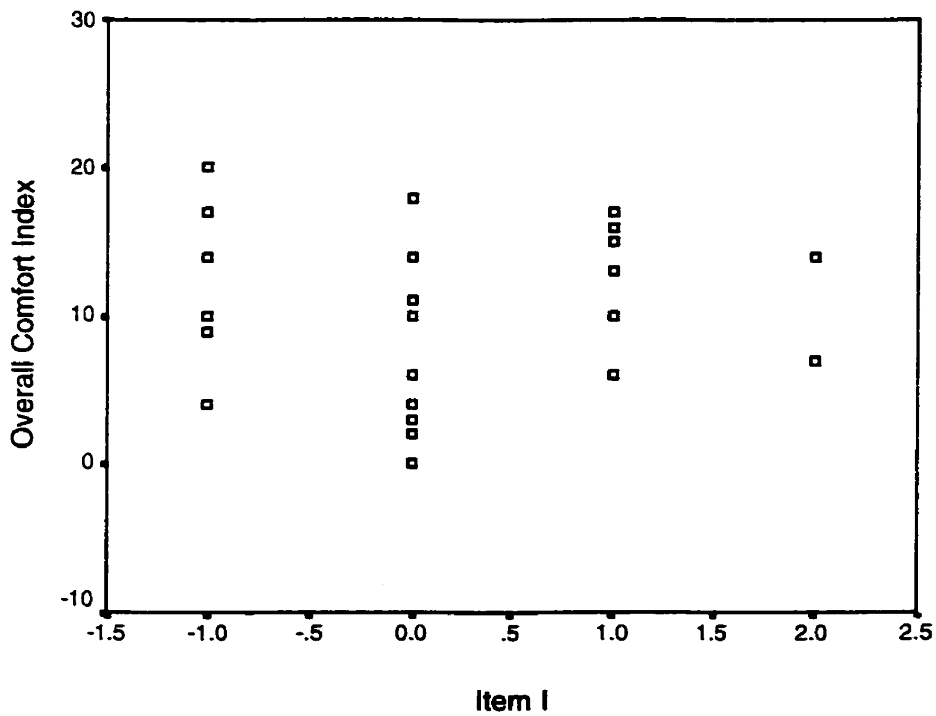


Figure 20: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item I)

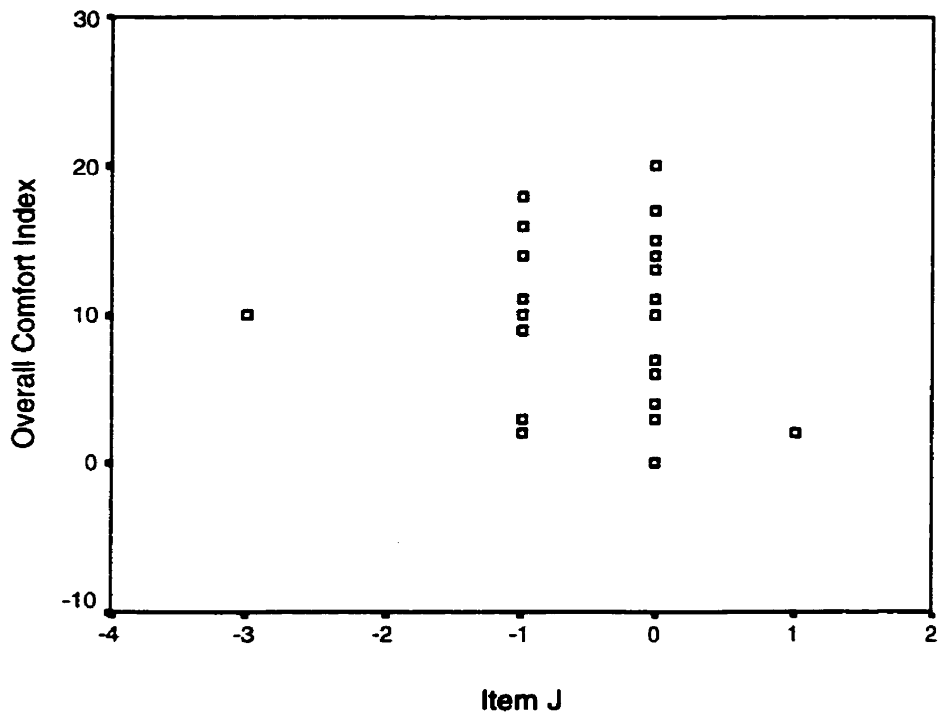


Figure 21: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item J)

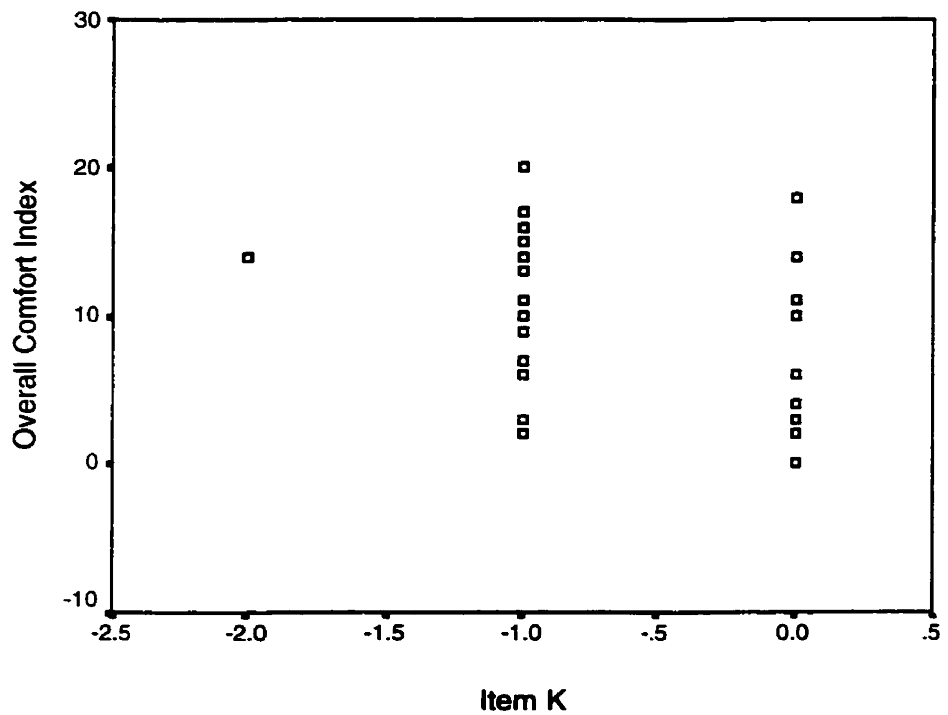


Figure 22: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item K)

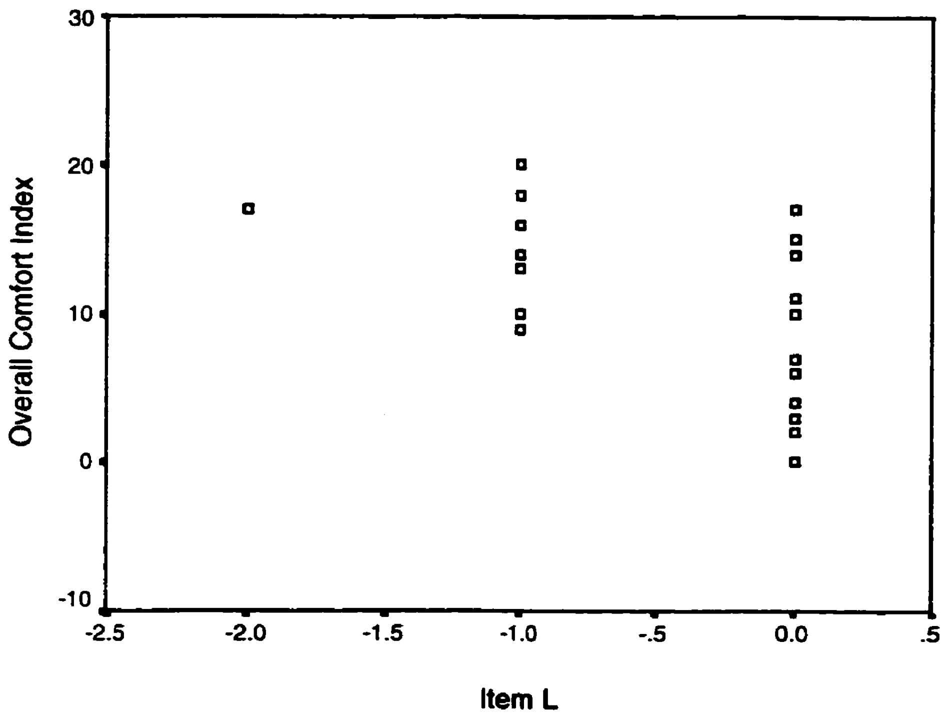


Figure 23: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item L)

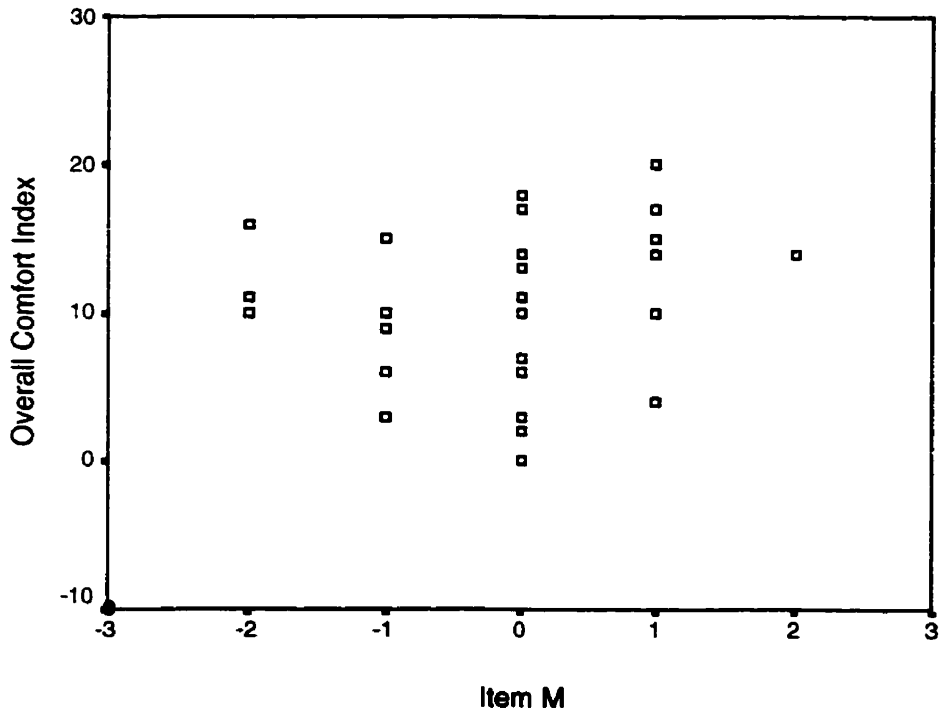


Figure 24: Scatter Plot for Criterion Related Validity (Overall Comfort Index vs. Item M)

Table 12: Criterion-Related Validity for Overall Comfort Index as a Function of Items from the First Revision of the Automobile Seat Comfort Survey presented in Table 10

Item	Model	r^2	df	F	Sig.
Appearance Rating	Linear	0.292*	28	11.54	0.002
A. Amount of Lumbar Support	Quadratic	0.347*	28	7.42	0.003
B. Lumbar Comfort	Linear	0.442*	30	23.72	0.000
C. Amount of Mid-Back Support	Quadratic	0.336*	29	7.34	0.003
D. Mid-Back Comfort	Linear	0.302*	30	12.98	0.001
E. Amount of Back Lateral Support	Quadratic	0.248*	29	4.79	0.016
F. Back Lateral Comfort	Linear	0.377*	30	17.13	0.000
G. Seat Back Feel / Firmness	Quadratic	0.237*	28	4.36	0.023
H. Ischial / Buttocks Comfort	Linear	0.139*	30	4.86	0.035
I. Amount of Thigh Support	Quadratic	0.084	29	1.33	0.281
J. Cushion Length	Quadratic	0.046	29	0.7	0.503
K. Thigh Comfort	Linear	0.166*	30	5.96	0.021
L. Cushion Lateral Comfort	Linear	0.314*	30	13.75	0.001
M. Cushion Feel / Firmness	Quadratic	0.112	29	1.84	0.177

*Model is significant at 0.05 level

From this analysis it is possible to eliminate Items I, J, and M. These items were reliable but they were not valid. This finding implies that, in terms of these three items, occupants responded identically in a test-retest scenario but their responses did not impact overall perceptions of seat comfort (as determined by the overall comfort index). The improved survey (final revision) is shown in Table 13.

Table 13: Final Revision of the Automobile Seat Comfort Survey

	Stop! Start Over	Poor, Major Improvements Needed	Fair, Minor Improvements Needed	Good, Slight Improvements Needed	World Class Seat
Overall Seat Appearance	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐

Item		**-3**	**-2**	**-1**	**Just Right**	**1**	**2**	**3**	
SEATBACK:									
A. Amount of Lumbar Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
B. Lumbar Comfort	uncomfortable	☐	☐	☐	☐				
C. Amount of Mid-Back Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
D. Mid-Back Comfort	uncomfortable	☐	☐	☐	☐				
E. Amount of Back Lateral Support	too little	☐	☐	☐	☐	☐	☐	☐	too much
F. Back Lateral Comfort	uncomfortable	☐	☐	☐	☐				
G. Seat Back Feel / Firmness	too soft	☐	☐	☐	☐	☐	☐	☐	too firm
CUSHION:									
H. Ischial / Buttocks Comfort	uncomfortable	☐	☐	☐	☐				too much
I. Thigh Comfort	uncomfortable	☐	☐	☐	☐				
J. Cushion Lateral Comfort	uncomfortable	☐	☐	☐	☐				

Construct validity is the most general of the various approaches to validity and refers to whether scores on a measure reflect the construct that it is purported to measure. Whereas the primary question in criterion-related validity is "Does the measure predict?", the primary question in construct validity is "What does the measure really measure?".

The data presented in Table 14 was used to assess construct validity. It represents the survey results of four subjects who evaluated Seat #1 (Trial A). These subjects were selected based on their overall comfort index scores. More specifically, in this seat, subject #2 and subject #3 were among the most comfortable (lowest scores) while subject #1 and subject #4 were among the least comfortable (highest scores). To assess whether or not the survey truly represents automobile seat comfort, the number of identical responses between the two comfortable subjects (#2 and #3), the comfortable subjects (#2 and #3) and the uncomfortable subjects (#1 and #4), and the uncomfortable subjects (#1 and #4) were counted. One would expect the number of identical responses between the like subjects to be fairly high and the number of identical responses between the unlike subjects to be low. This analysis, basically, amounts to an assessment of construct validity.

Table 14: Ratings from Comfortable and Uncomfortable Subjects used to Assess Construct Validity

Item	Subject #1	Subject #2	Subject #3	Subject #4
A. Amount of Lumbar Support	1	0	1	1
B. Lumbar Comfort	-1	-1	-1	-1
C. Amount of Mid-Back Support	-1	0	0	-1
D. Mid-Back Comfort	-1	0	0	-1
E. Amount of Back Lateral Support	-1	0	0	0
F. Back Lateral Comfort	-1	0	0	-1
G. Seat Back Feel / Firmness	1	0	0	2
H. Ischial / Buttocks Comfort	-1	0	0	-1
I. Thigh Comfort	-1	0	0	-1
J. Cushion Lateral Comfort	0	0	0	-1
Overall Comfort Index	9	1	2	10

The two comfortable subjects (subject #2 and #3) responded identically on seven of the 10 items. Similarly, the two uncomfortable subjects (subject #1 and #4) responded identically on seven of the 10 items. When comparing all possible combinations of comfortable subjects and uncomfortable subjects (i.e., subject #1 vs. subject #2, subject #1 vs. subject #3, subject #2 vs. subject #4, and subject #3 vs. subject #4), the highest identical response rate was only three of 10 items (subject #1 vs subject #3 and subject #3 vs. subject #4). Even the appearance rating data shows similar trends. Therefore, this instrument has decent construct validity.

Another perspective to be considered is face validity, or the extent to which a predictor looks valid. While not a substitute for other kinds of validity, face validity can have a bearing on how subjects react to the survey, and therefore, how meaningful their responses are. There is no disputing the fact that items included in Table 13 have high face validity. The survey in Table 13 will, therefore, be used for the remainder of this research.

To demonstrate its applicability, 12 subjects evaluated the front driver seat of five vehicles using the survey. The survey results are included in Appendix B. The structured analysis approach, outlined in this section, is recommended for all seat comfort development initiatives that are based, wholly or in part, on survey data. The first step in the analysis is to compute descriptive statistics for all survey variables. This was done in Table 15.

Table 15: Descriptive Statistics for Individual Survey Items

SEAT		Overall Comfort Index	A. Amount of Lumbar Support	B. Lumbar Comfort	C. Amount of Mid-Back Support	D. Mid-Back Comfort	E. Amount of Back Lateral Support	F. Back Lateral Comfort	G. Seat Back Feel / Firmness	H. Ischial / Buttocks Comfort	I. Thigh Comfort	J. Cushion Lateral Comfort
A	Mean	6.0	-0.8	-0.6	-0.6	-0.4	-0.5	-0.7	-0.4	-0.2	-0.8	-0.7
	N	12	12	12	12	12	12	12	12	12	12	12
	STD	2.2	0.6	0.7	0.5	0.5	0.7	0.5	0.7	0.4	0.7	0.5
	Min	3	-2	-2	-1	-1	-1	-1	-1	-1	-2	-1
	Max	11	0	0	0	0	1	0	1	0	0	0
B	Mean	10.3	-1.0	-1.3	-0.8	-0.7	-1.0	-1.1	-1.2	-0.8	-1.4	-0.8
	N	12	12	12	12	12	12	12	12	12	12	12
	STD	1.9	0.9	0.5	0.6	0.7	0.6	0.7	0.7	0.9	0.8	0.5
	Min	7	-2	-2	-2	-2	-2	-2	-2	-2	-3	-1
	Max	13	1	-1	0	0	0	0	0	1	0	0
C	Mean	2.3	-0.2	-0.2	0.3	-0.3	-0.3	-0.3	0.3	-0.2	-0.2	-0.1
	N	12	12	12	12	12	12	12	12	12	12	12
	STD	1.1	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.5
	Min	1	-1	-1	0	-1	-1	-1	0	-1	-1	-1
	Max	4	0	0	1	0	0	0	1	0	0	1
D	Mean	8.6	-0.3	-0.7	-0.3	-0.8	-0.8	-0.8	-0.1	-0.7	-1.3	-0.7
	N	12	12	12	12	12	12	12	12	12	12	12
	STD	1.3	0.9	0.5	1.1	0.7	0.8	0.6	1.2	0.5	0.9	0.5
	Min	6	-1	-1	-2	-2	-2	-2	-2	-1	-3	-1
	Max	10	1	0	2	0	1	0	2	0	0	0
E	Mean	12.8	-1.0	-1.4	0.1	-1.1	-1.3	-1.4	0.3	-1.3	-1.4	-1.3
	N	12	12	12	12	12	12	12	12	12	12	12
	STD	1.4	1.0	0.7	1.0	0.3	0.9	0.5	1.1	0.5	0.5	0.7
	Min	10	-2	-3	-1	-2	-2	-2	-1	-2	-2	-2
	Max	15	2	-1	1	-1	1	-1	2	-1	-1	0
Total	Mean	8.0	-0.7	-0.8	-0.3	-0.7	-0.8	-0.9	-0.2	-0.6	-1.0	-0.7
	N	60	60	60	60	60	60	60	60	60	60	60
	STD	4.0	0.8	0.7	0.9	0.6	0.8	0.7	1.0	0.7	0.8	0.6
	Min	1	-2	-3	-2	-2	-2	-2	-2	-2	-3	-2
	Max	15	2	0	2	0	1	0	2	1	0	1

Next, it is essential to determine if the differences outlined in Table 15 are statistically significant. This is important because it prevents unnecessary design changes. That is, it is senseless to make a change based on an effect that does not, in reality, exist. The type of statistical analysis employed is dependent on the manner in which data was collected. Purists may even apply non-parametric statistics. They should, however, be prepared to address questions posed by those unfamiliar with the chosen test statistic. The approach taken in this manuscript is to test the hypothesis that the means outlined in Table 15 are equal. A one-way ANOVA is, therefore, appropriate. The results are shown in Table 16.

Table 16: One-Way ANOVA for Survey Item Differences between Seats

		Sum of Squares	df	Mean Square	F	Sig.
Overall Comfort Index	Between Seats	780.267	4	195.067	74.677	0.000
	Within Seats	143.667	55	2.612		
	Total	923.933	59			
A. Amount of Lumbar Support	Between Seats	8.067	4	2.017	3.303	0.017
	Within Seats	33.583	55	0.611		
	Total	41.650	59			
B. Lumbar Comfort	Between Seats	13.500	4	3.375	11.027	0.000
	Within Seats	16.833	55	0.306		
	Total	30.333	59			
C. Amount of Mid-Back Support	Between Seats	8.667	4	2.167	3.446	0.014
	Within Seats	34.583	55	0.629		
	Total	43.250	59			
D. Mid-Back Comfort	Between Seats	5.233	4	1.308	4.383	0.004
	Within Seats	16.417	55	0.298		
	Total	21.650	59			
E. Amount of Back Lateral Support	Between Seats	7.567	4	1.892	3.830	0.008
	Within Seats	27.167	55	0.494		
	Total	34.733	59			
F. Back Lateral Comfort	Between Seats	9.233	4	2.308	7.734	0.000
	Within Seats	16.417	55	0.298		
	Total	25.650	59			
G. Seat Back Feel / Firmness	Between Seats	17.767	4	4.442	5.759	0.001
	Within Seats	42.417	55	0.771		
	Total	60.183	59			
H. Ischial / Buttocks Comfort	Between Seats	9.900	4	2.475	8.250	0.000
	Within Seats	16.500	55	0.300		
	Total	26.400	59			
I. Thigh Comfort	Between Seats	14.100	4	3.525	7.505	0.000
	Within Seats	25.833	55	0.470		
	Total	39.933	59			
J. Cushion Lateral Comfort	Between Seats	9.433	4	2.358	8.552	0.000
	Within Seats	15.167	55	0.276		
	Total	24.600	59			

The results reveal that there is a difference between the seats (decision criterion of .05). This is the case for the overall comfort index, as well as the individual survey items. The one-way ANOVA does not, however, reveal exactly which seats differ. To this end, it is necessary to apply a post-hoc test. For the purposes of this study, Dunnett's C Test was used to demonstrate exactly which pairs of seats were statistically different (in terms of the overall comfort index). Dunnett's C Test can justifiably be applied because the group variances are unequal (refer to Table 15). The post-hoc test results, for the overall comfort index, are shown in Table 17.

Table 17: Dunnett's C Test for Differences in Overall Comfort Index

(I) SEAT	(J) SEAT	Mean Difference (I-J)		Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
A	B	-4.25	*	0.66	0.00	-6.95	-1.55
	C	3.75	*	0.66	0.00	1.46	6.04
	D	-2.58	*	0.66	0.00	-4.99	-0.18
	E	-6.75	*	0.66	0.00	-9.18	-4.32
B	A	4.25	*	0.66	0.00	1.55	6.95
	C	8.00	*	0.66	0.00	6.00	10.00
	D	1.67		0.66	0.00	-0.46	3.79
	E	-2.50	*	0.66	0.00	-4.65	-0.35
C	A	-3.75	*	0.66	0.00	-6.04	-1.46
	B	-8.00	*	0.66	0.00	-10.00	-6.00
	D	-6.33	*	0.66	0.00	-7.90	-4.76
	E	-10.50	*	0.66	0.00	-12.10	-8.90
D	A	2.58	*	0.66	0.00	0.18	4.99
	B	-1.67		0.66	0.00	-3.79	0.46
	C	6.33	*	0.66	0.00	4.76	7.90
	E	-4.17	*	0.66	0.00	-5.93	-2.41
E	A	6.75	*	0.66	0.00	4.32	9.18
	B	2.50	*	0.66	0.00	0.35	4.65
	C	10.50	*	0.66	0.00	8.90	12.10
	D	4.17	*	0.66	0.00	2.41	5.93

*The mean difference is significant at the .05 level.

All of the seats were different (at the .05 level) except for Seat B and Seat D. Referring to the descriptive statistics in Table 15, it is possible to conclude that Seat C (mean overall comfort index = 2.25) is the most comfortable, followed by Seat A (mean overall comfort index = 6.00). Seat E is, definitely, the least comfortable (mean overall comfort index of 12.75).

A more in-depth investigation into the reason for the difference in overall comfort index can be performed by analyzing each survey item individually. The resulting information, because it is focused on specific regions of the seat, can be used to improve Seat E (least comfortable) relative to Seat C (most comfortable). Dunnett's C Test was used to determine if there were survey item differences between the two seats (Table 18 to Table 22).

Table 18: Dunnett's C Test for Differences in Survey Item A and Survey Item B

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Item A. Amount of Lumbar Support	A	B	0.17	0.32	0.00	-0.79	1.13
		C	-0.67 *	0.32	0.00	-1.32	-0.02
		D	-0.58	0.32	0.00	-1.56	0.39
		E	0.17	0.32	0.00	-0.95	1.28
	B	A	-0.17	0.32	0.00	-1.13	0.79
		C	-0.83	0.32	0.00	-1.71	0.04
		D	-0.75	0.32	0.00	-1.88	0.38
		E	0.00	0.32	0.00	-1.26	1.26
	C	A	0.67 *	0.32	0.00	0.02	1.32
		B	0.83	0.32	0.00	-0.04	1.71
		D	0.08	0.32	0.00	-0.80	0.97
		E	0.83	0.32	0.00	-0.21	1.87
	D	A	0.58	0.32	0.00	-0.39	1.56
		B	0.75	0.32	0.00	-0.38	1.88
		C	-0.08	0.32	0.00	-0.97	0.80
		E	0.75	0.32	0.00	-0.52	2.02
	E	A	-0.17	0.32	0.00	-1.28	0.95
		B	0.00	0.32	0.00	-1.26	1.26
		C	-0.83	0.32	0.00	-1.87	0.21
		D	-0.75	0.32	0.00	-2.02	0.52
Item B. Lumbar Comfort	A	B	0.75	0.23	0.00	-0.03	1.53
		C	-0.42	0.23	0.00	-1.14	0.31
		D	0.08	0.23	0.00	-0.69	0.86
		E	0.83	0.23	0.00	-0.05	1.72
	B	A	-0.75	0.23	0.00	-1.53	0.03
		C	-1.17 *	0.23	0.00	-1.75	-0.58
		D	-0.67 *	0.23	0.00	-1.32	-0.02
		E	0.08	0.23	0.00	-0.69	0.86
	C	A	0.42	0.23	0.00	-0.31	1.14
		B	1.17 *	0.23	0.00	0.58	1.75
		D	0.50	0.23	0.00	-0.09	1.09
		E	1.25 *	0.23	0.00	0.53	1.97
	D	A	-0.08	0.23	0.00	-0.86	0.69
		B	0.67 *	0.23	0.00	0.02	1.32
		C	-0.50	0.23	0.00	-1.09	0.09
		E	0.75	0.23	0.00	-0.03	1.53
	E	A	-0.83	0.23	0.00	-1.72	0.05
		B	-0.08	0.23	0.00	-0.86	0.69
		C	-1.25 *	0.23	0.00	-1.97	-0.53
		D	-0.75	0.23	0.00	-1.53	0.03

*The mean difference is significant at the .05 level.

Table 19: Dunnett's C Test for Differences in Survey Item C and Survey Item D

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Item C. Amount of Mid-Back Support	A	B	0.17	0.32	0.00	-0.59	0.92
		C	-0.83*	0.32	0.00	-1.47	-0.19
		D	-0.33	0.32	0.00	-1.50	0.83
		E	-0.67	0.32	0.00	-1.71	0.38
	B	A	-0.17	0.32	0.00	-0.92	0.59
		C	-1.00*	0.32	0.00	-1.72	-0.28
		D	-0.50	0.32	0.00	-1.71	0.71
		E	-0.83	0.32	0.00	-1.93	0.26
	C	A	0.83*	0.32	0.00	0.19	1.47
		B	1.00*	0.32	0.00	0.28	1.72
		D	0.50	0.32	0.00	-0.64	1.64
		E	0.17	0.32	0.00	-0.85	1.19
	D	A	0.33	0.32	0.00	-0.83	1.50
		B	0.50	0.32	0.00	-0.71	1.71
		C	-0.50	0.32	0.00	-1.64	0.64
		E	-0.33	0.32	0.00	-1.75	1.08
	E	A	0.67	0.32	0.00	-0.38	1.71
		B	0.83	0.32	0.00	-0.26	1.93
		C	-0.17	0.32	0.00	-1.19	0.85
		D	0.33	0.32	0.00	-1.08	1.75
Item D. Mid-Back Comfort	A	B	0.25	0.22	0.00	-0.53	1.03
		C	-0.17	0.22	0.00	-0.81	0.47
		D	0.42	0.22	0.00	-0.41	1.24
		E	0.67*	0.22	0.00	0.12	1.22
	B	A	-0.25	0.22	0.00	-1.03	0.53
		C	-0.42	0.22	0.00	-1.16	0.32
		D	0.17	0.22	0.00	-0.74	1.07
		E	0.42	0.22	0.00	-0.25	1.08
	C	A	0.17	0.22	0.00	-0.47	0.81
		B	0.42	0.22	0.00	-0.32	1.16
		D	0.58	0.22	0.00	-0.21	1.38
		E	0.83*	0.22	0.00	0.33	1.33
	D	A	-0.42	0.22	0.00	-1.24	0.41
		B	-0.17	0.22	0.00	-1.07	0.74
		C	-0.58	0.22	0.00	-1.38	0.21
		E	0.25	0.22	0.00	-0.47	0.97
	E	A	-0.67*	0.22	0.00	-1.22	-0.12
		B	-0.42	0.22	0.00	-1.08	0.25
		C	-0.83*	0.22	0.00	-1.33	-0.33
		D	-0.25	0.22	0.00	-0.97	0.47

*The mean difference is significant at the .05 level.

Table 20: Dunnett's C Test for Differences in Survey Item E and Survey Item F

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Item E. Amount of Back Lateral Support	A	B	0.50	0.29	0.00	-0.34	1.34
		C	-0.25	0.29	0.00	-1.01	0.51
		D	0.33	0.29	0.00	-0.67	1.34
		E	0.75	0.29	0.00	-0.27	1.77
	B	A	-0.50	0.29	0.00	-1.34	0.34
		C	-0.75*	0.29	0.00	-1.45	-0.05
		D	-0.17	0.29	0.00	-1.13	0.79
		E	0.25	0.29	0.00	-0.74	1.24
	C	A	0.25	0.29	0.00	-0.51	1.01
		B	0.75*	0.29	0.00	0.05	1.45
		D	0.58	0.29	0.00	-0.30	1.47
		E	1.00*	0.29	0.00	0.09	1.91
	D	A	-0.33	0.29	0.00	-1.34	0.67
		B	0.17	0.29	0.00	-0.79	1.13
		C	-0.58	0.29	0.00	-1.47	0.30
		E	0.42	0.29	0.00	-0.71	1.54
	E	A	-0.75	0.29	0.00	-1.77	0.27
		B	-0.25	0.29	0.00	-1.24	0.74
		C	-1.00*	0.29	0.00	-1.91	-0.09
		D	-0.42	0.29	0.00	-1.54	0.71
Item F. Back Lateral Comfort	A	B	0.42	0.22	0.00	-0.36	1.19
		C	-0.42	0.22	0.00	-1.04	0.21
		D	0.17	0.22	0.00	-0.54	0.88
		E	0.75*	0.22	0.00	0.08	1.42
	B	A	-0.42	0.22	0.00	-1.19	0.36
		C	-0.83*	0.22	0.00	-1.59	-0.08
		D	-0.25	0.22	0.00	-1.07	0.57
		E	0.33	0.22	0.00	-0.45	1.12
	C	A	0.42	0.22	0.00	-0.21	1.04
		B	0.83*	0.22	0.00	0.08	1.59
		D	0.58	0.22	0.00	-0.10	1.27
		E	1.17*	0.22	0.00	0.53	1.81
	D	A	-0.17	0.22	0.00	-0.88	0.54
		B	0.25	0.22	0.00	-0.57	1.07
		C	-0.58	0.22	0.00	-1.27	0.10
		E	0.58	0.22	0.00	-0.14	1.31
	E	A	-0.75*	0.22	0.00	-1.42	-0.08
		B	-0.33	0.22	0.00	-1.12	0.45
		C	-1.17*	0.22	0.00	-1.81	-0.53
		D	-0.58	0.22	0.00	-1.31	0.14

*The mean difference is significant at the .05 level.

Table 21: Dunnett's C Test for Differences in Survey Item G and Survey Item H

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Item G. Seat Back Feel / Firmness	A	B	0.75	0.36	0.00	-0.17	1.67
		C	-0.75	0.36	0.00	-1.53	0.03
		D	-0.33	0.36	0.00	-1.59	0.92
		E	-0.67	0.36	0.00	-1.90	0.57
	B	A	-0.75	0.36	0.00	-1.67	0.17
		C	-1.50*	0.36	0.00	-2.31	-0.69
		D	-1.08	0.36	0.00	-2.36	0.19
		E	-1.42*	0.36	0.00	-2.67	-0.16
	C	A	0.75	0.36	0.00	-0.03	1.53
		B	1.50*	0.36	0.00	0.69	2.31
		D	0.42	0.36	0.00	-0.76	1.60
		E	0.08	0.36	0.00	-1.07	1.24
	D	A	0.33	0.36	0.00	-0.92	1.59
		B	1.08	0.36	0.00	-0.19	2.36
		C	-0.42	0.36	0.00	-1.60	0.76
		E	-0.33	0.36	0.00	-1.85	1.19
	E	A	0.67	0.36	0.00	-0.57	1.90
		B	1.42*	0.36	0.00	0.16	2.67
		C	-0.08	0.36	0.00	-1.24	1.07
		D	0.33	0.36	0.00	-1.19	1.85
Item H. Ischial / Buttocks Comfort	A	B	0.58	0.22	0.00	-0.30	1.47
		C	0.00	0.22	0.00	-0.51	0.51
		D	0.50	0.22	0.00	-0.09	1.09
		E	1.08*	0.22	0.00	0.53	1.64
	B	A	-0.58	0.22	0.00	-1.47	0.30
		C	-0.58	0.22	0.00	-1.47	0.30
		D	-0.08	0.22	0.00	-1.01	0.85
		E	0.50	0.22	0.00	-0.41	1.41
	C	A	0.00	0.22	0.00	-0.51	0.51
		B	0.58	0.22	0.00	-0.30	1.47
		D	0.50	0.22	0.00	-0.09	1.09
		E	1.08*	0.22	0.00	0.53	1.64
	D	A	-0.50	0.22	0.00	-1.09	0.09
		B	0.08	0.22	0.00	-0.85	1.01
		C	-0.50	0.22	0.00	-1.09	0.09
		E	0.58	0.22	0.00	-0.04	1.21
	E	A	-1.08*	0.22	0.00	-1.64	-0.53
		B	-0.50	0.22	0.00	-1.41	0.41
		C	-1.08*	0.22	0.00	-1.64	-0.53
		D	-0.58	0.22	0.00	-1.21	0.04

*The mean difference is significant at the .05 level.

Table 22: Dunnett's C Test for Differences in Survey Item I and Survey Item J

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Item I. Thigh Comfort	A	B	0.58	0.28	0.00	-0.42	1.58
		C	-0.67	0.28	0.00	-1.43	0.10
		D	0.50	0.28	0.00	-0.57	1.57
		E	0.58	0.28	0.00	-0.24	1.41
	B	A	-0.58	0.28	0.00	-1.58	0.42
		C	-1.25 *	0.28	0.00	-2.07	-0.43
		D	-0.08	0.28	0.00	-1.19	1.03
		E	0.00	0.28	0.00	-0.88	0.88
	C	A	0.67	0.28	0.00	-0.10	1.43
		B	1.25 *	0.28	0.00	0.43	2.07
		D	1.17 *	0.28	0.00	0.26	2.07
		E	1.25 *	0.28	0.00	0.65	1.85
	D	A	-0.50	0.28	0.00	-1.57	0.57
		B	0.08	0.28	0.00	-1.03	1.19
		C	-1.17 *	0.28	0.00	-2.07	-0.26
		E	0.08	0.28	0.00	-0.87	1.04
	E	A	-0.58	0.28	0.00	-1.41	0.24
		B	0.00	0.28	0.00	-0.88	0.88
		C	-1.25 *	0.28	0.00	-1.85	-0.65
		D	-0.08	0.28	0.00	-1.04	0.87
Item J. Cushion Lateral Comfort	A	B	0.08	0.21	0.00	-0.54	0.71
		C	-0.58	0.21	0.00	-1.25	0.08
		D	0.00	0.21	0.00	-0.65	0.65
		E	0.67	0.21	0.00	-0.10	1.43
	B	A	-0.08	0.21	0.00	-0.71	0.54
		C	-0.67 *	0.21	0.00	-1.31	-0.03
		D	-0.08	0.21	0.00	-0.71	0.54
		E	0.58	0.21	0.00	-0.16	1.32
	C	A	0.58	0.21	0.00	-0.08	1.25
		B	0.67 *	0.21	0.00	0.03	1.31
		D	0.58	0.21	0.00	-0.08	1.25
		E	1.25 *	0.21	0.00	0.47	2.03
	D	A	0.00	0.21	0.00	-0.65	0.65
		B	0.08	0.21	0.00	-0.54	0.71
		C	-0.58	0.21	0.00	-1.25	0.08
		E	0.67	0.21	0.00	-0.10	1.43
	E	A	-0.67	0.21	0.00	-1.43	0.10
		B	-0.58	0.21	0.00	-1.32	0.16
		C	-1.25 *	0.21	0.00	-2.03	-0.47
		D	-0.67	0.21	0.00	-1.43	0.10

*The mean difference is significant at the .05 level.

This data reveal that respondents found Seat E lacking in terms of lumbar comfort (as per Item B – Table 18), mid back comfort (as per Item D – Table 19), back lateral comfort (as per Item E and F – Table 20), ischial comfort (as per Item H – Table 21), thigh comfort (as per Item I – Table 22), and cushion lateral comfort (as per Item J – Table 22). From a design recommendation perspective, the survey can be used to conclude that the amount of lumbar support provided by Seat E is not the issue (as per Item A – Table 18). In other words, the amount of lumbar prominence is, probably, appropriately set or, at least, comparable to Seat C (the most comfortable seat). The problem may be related to a trim construction characteristic located in the lumbar region. The survey revealed that Seat E provided insufficient back lateral support (as per Item E – Table 20). Possible remedies include increasing the wing height, decreasing the insert width, or providing a steeper wing angle. Lastly, since there was no difference in perceptions of seatback firmness between the best seat (i.e., Seat C) and Seat E (as per Item G – Table 21), modifying foam firmness should not be considered an option that would improve comfort.

Interestingly enough, the rank order of the five case study seats (based on the overall comfort index) was identical to that found in the J.D. Power & Associates TGR data. The seat TGR score is derived from 16 questions on the APEAL survey. This survey addresses what new owners liked about the seats in their new vehicles. The fact that the survey results match the data reported by J.D. Power & Associates (for the appropriate model year) was an expected result because five of the 16 questions are directly related to front seat comfort. They are: (1) driver's seat adjustability, (2) driver's seat – lower back support, (3) driver's seat – comfort on long trips, (4) driver's seat – comfort on short trips, and (5) driver's seat – holds you cornering.

The same five seats and 12 subjects were used to study the effect of appearance on perceptions of overall comfort. The descriptive statistics are shown in Table 23.

Table 23: Descriptive Statistics for Appearance Ratings

		Appearance Rating
Seat A	Mean	3.8
	N	12
	STD	0.7
	Min	2.5
	Max	4.5
Seat B	Mean	2.8
	N	12
	STD	0.6
	Min	2.0
	Max	4.0
Seat C	Mean	4.4
	N	12
	STD	0.6
	Min	3.0
	Max	5.0
Seat D	Mean	3.8
	N	12
	STD	1.0
	Min	2.5
	Max	5.0
Seat E	Mean	3.2
	N	12
	STD	0.7
	Min	2.0
	Max	4.5
Total	Mean	3.6
	N	60
	STD	0.9
	Min	2.0
	Max	5.0

To determine if the appearance ratings were statistically different between the seats, a one-way ANOVA was performed. The results are shown in Table 24.

Table 24: One-Way ANOVA for Appearance Rating Differences between Seats

		Sum of Squares	df	Mean Square	F	Sig.
Appearance Rating	Between Seats	18.400	4	4.600	8.680	0.000
	Within Seats	29.146	55	0.530		
	Total	47.546	59			

Table 24 reveals that the difference in appearance ratings between the five seats was statistically significant at the .05 level. Dunnett's C Test was used to determine exactly which means were different. The results are shown in Table 25.

Table 25: Dunnett's C Test for Differences in Appearance Rating

(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	0.96 *	0.30	0.00	0.07	1.84
	C	-0.63	0.30	0.00	-1.50	0.25
	D	-0.04	0.30	0.00	-1.16	1.08
	E	0.63	0.30	0.00	-0.30	1.55
B	A	-0.96 *	0.30	0.00	-1.84	-0.07
	C	-1.58 *	0.30	0.00	-2.38	-0.78
	D	-1.00	0.30	0.00	-2.07	0.07
	E	-0.33	0.30	0.00	-1.19	0.53
C	A	0.63	0.30	0.00	-0.25	1.50
	B	1.58 *	0.30	0.00	0.78	2.38
	D	0.58	0.30	0.00	-0.47	1.64
	E	1.25 *	0.30	0.00	0.40	2.10
D	A	0.04	0.30	0.00	-1.08	1.16
	B	1.00	0.30	0.00	-0.07	2.07
	C	-0.58	0.30	0.00	-1.64	0.47
	E	0.67	0.30	0.00	-0.44	1.77
E	A	-0.63	0.30	0.00	-1.55	0.30
	B	0.33	0.30	0.00	-0.53	1.19
	C	-1.25 *	0.30	0.00	-2.10	-0.40
	D	-0.67	0.30	0.00	-1.77	0.44

*The mean difference is significant at the .05 level.

Considering the post hoc results (Table 25) in combination with the means outlined in Table 23, Seat B was rated as less aesthetically pleasing than Seat A and Seat C. In the same way, Seat C was rated as more attractive than Seat B and Seat E. In general, Seat B was the least favorite while Seat C was the most favorite. As an interesting aside, Seat C was, according to the overall comfort index, rated as most comfortable. Further examination into the relationship between appearance and comfort is, therefore, necessary.

The quantification of linear trend is called correlation, and, for the purposes of this dissertation, it is reflected in the value of a statistic called the Pearson product moment correlation coefficient, or, more commonly, the Pearson r. The Pearson r is written as r_{XY} and is read as the correlation between variables X and Y. It is common for the correlation statistic to be reported along with an analysis of regression, because it provides an extra dimension of descriptive power regarding the strength of the functional relationship between two or more variables. The correlation analysis was done first because it makes sense to determine if there is any relationship between two variables before one tries to use this relationship for prediction purposes. In this context, it was found that the correlation between the overall comfort index and appearance rating was statistically significant [$\underline{r}$ (60) = -.645, $\underline{p}$ = .000].

4.2 Scientific Method for Quantifying Automobile Seat Comfort

Descriptive statistics for the repeatability of the sensor array data are shown in Table 26, whereas the statistical mean comparison is shown in Table 27. In terms of the seat interface pressure measurements, the results suggest that there is no statistically significant difference between the test and retest conditions (at the .05 level). That is, static pressure distribution measures are repeatable. This is an important result because it justifies the selection of seat interface pressure as this study's objective measure of comfort.

It can be speculated that consistency could be further improved by controlling seat position. Recall that in this study subjects could, if necessary, adjust any and all seat features in both conditions. The assumption was that subjects are consistent in their selection of seat position.

Table 26: Descriptive Statistics for Test-Retest Reliability of Sensor Arrays used for Seat Interface Pressure Determination

Pressure Measure	Condition	Mean	N	STD
CCA (cm^2)	Test	1689	17	92
	Retest	1696	17	93
CTF (N)	Test	647	17	120
	Retest	632	17	143
CCF (g/cm^2)	Test	41	17	19
	Retest	45	17	26
BCA (cm^2)	Test	1214	17	297
	Retest	1266	17	268
BTF (N)	Test	224	17	63
	Retest	214	17	54
BCF (g/cm^2)	Test	34	17	22
	Retest	37	17	26

Table 27: Paired Samples t-test for Test-Retest Reliability of Sensor Arrays used for Seat Interface Pressure Determination

	Paired Differences			95% Confidence Interval of the Difference				
Pressure Measure	Mean	STD	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
CCA (Test - Retest)	-6.7	45.0	10.9	-29.9	16.4	-0.617	16	0.546
CTF (Test - Retest)	15.0	75.3	18.3	-23.7	53.7	0.822	16	0.423
CCF (Test - Retest)	-3.5	18.4	4.5	-12.9	6.0	-0.777	16	0.449
BCA (Test - Retest)	-52.3	129.2	31.3	-118.8	14.1	-1.670	16	0.114
BTF (Test - Retest)	9.8	27.6	6.7	-4.4	23.9	1.462	16	0.163
BCF (Test - Retest)	-2.2	17.2	4.2	-11.1	6.6	-0.538	16	0.598

4.3 Driver Selected Seat Position

The driver selected seat position data are included in Appendix C. Table 28 provides the mean, standard deviation, minimum, and maximum track position and seatback angle for Seat A, Seat C, and Seat D.

Table 28: Descriptive Statistics for Driver Selected Seat Position

Seat		Track Position (mm)	Seatback Angle (°)
A	Mean	827	16
	N	12	12
	STD	76	4
	Min	716	9
	Max	917	24
C	Mean	836	16
	N	12	12
	STD	68	2
	Min	688	14
	Max	898	22
D	Mean	823	11
	N	12	12
	STD	61	2
	Min	702	8
	Max	872	14
Total	Mean	829	14
	N	36	36
	STD	67	4
	Min	688	8
	Max	917	24

The minimum and maximum data outlined in Table 28 suggests that, in some vehicle packages, the entire track travel is not required. In Seat D, for example, due to a combination of packaging parameters like seat height, cushion angle, and pedal location, occupants representing a broad range of body sizes only used 170 mm of travel. The track was designed with a travel of 230 mm. Although less pronounced, a similar effect was found with Seat A (i.e., only 201 mm of the 220 mm track travel was used). The entire track travel was used for Seat C. Before concluding that Seat C has the only appropriately designed track, it is important to realize that track travel is not solely a comfort consideration. In some vehicle interior environments, track travel is extended to allow for improved cargo management (i.e., storage space). Nevertheless, since it is, relatively speaking, less expensive to design a track with less travel, this finding may provide justification for designing a lower cost track and, consequently, seat system.

It is, however, interesting to note that in every seat, at least three occupants sat with the track set to full rear. Only in Seat C did anyone sit full forward (i.e., one small female). Given this finding, seat manufacturers may be wise to consider extending the rearward track travel. This is, of course, dependent on interior space or, more specifically, the second row occupant's knee clearance requirements.

Driver preferred seatback angle is primarily dependent on vision requirements and steering wheel location. Table 28 reveals that preferences in seatback angle can be accommodated by providing between 8° (minimum for Seat D) and 24° (maximum for Seat A) of adjustment from vertical.

A one-way ANOVA was used to determine if the differences in Table 28 were statistically significant. The dependent factors were seatback angle and track position while the independent factor was seat type (i.e., Seat A, Seat C, and Seat D). The results are included in Table 29.

Table 29: ANOVA Summary Table for Differences in Driver Selected Seat Position Differences between Seats

		Sum of Squares	df	Mean Square	F	Sig.
Track Position (mm)	Between Seats	1167.389	2	583.694	0.125	0.883
	Within Seats	154418.250	33	4679.341		
	Total	155585.639	35			
Seatback Angle (°)	Between Seats	150.264	2	75.132	8.010	0.001
	Within Seats	309.542	33	9.380		
	Total	459.806	35			

Using a decision criterion of .05, seatback angle resulted in a statistically significant difference between seats. The same cannot be said for track position. Therefore, seat height, cushion angle, and pedal location (thought to determine track position) were probably similar between vehicles. Vision requirements and steering wheel location (thought to determine seatback angle) were probably different between vehicles.

Dunnett's C Test was used to determine exactly which seatback angle means were different. The results are presented in Table 30.

Table 30: Dunnett's C Test for Differences in Driver Selected Seatback Angle

(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	C	-0.083	1.250	0.000	-3.883	3.717
	D	4.292 *	1.250	0.000	0.605	7.979
C	A	0.083	1.250	0.000	-3.717	3.883
	D	4.375 *	1.250	0.000	1.889	6.861
D	A	-4.292 *	1.250	0.000	-7.979	-0.605
	C	-4.375 *	1.250	0.000	-6.861	-1.889

*The mean difference is significant at the .05 level.

The results suggest that occupants sat more upright in Seat D (mean seatback angle = 11°) than in either Seat A (mean seatback angle = 16°) or Seat C (mean seatback angle = 16°). The mean values were obtained from Table 28. Driver selected seatback angle, therefore, appears to be dependent on the particular vehicle. This finding precludes the formation of compact-car-specific recommendations for seatback angle starting positions.

It may, however, be possible to recommend, on a compact-car-specific level, a comfortable track position as a function of demographic and anthropometric characteristics. This statement is made based on the fact that there was no difference found in track position settings for the three seats included in this study (Table 29). Given this finding, the balance of this section is geared toward (1) developing a model to predict track position from subject level characteristics and (2) discussing how occupants should adjust seats for maximum comfort.

The data cannot be modeled without an understanding of the relationship between gender, standing height, and body mass (the prediction variables) and driver selected track position (the dependent variable). Scatter plots were used for this purpose. The results are included in Figure 25 (recall that females were assigned a zero and males were assigned a one), Figure 26, and Figure 27.

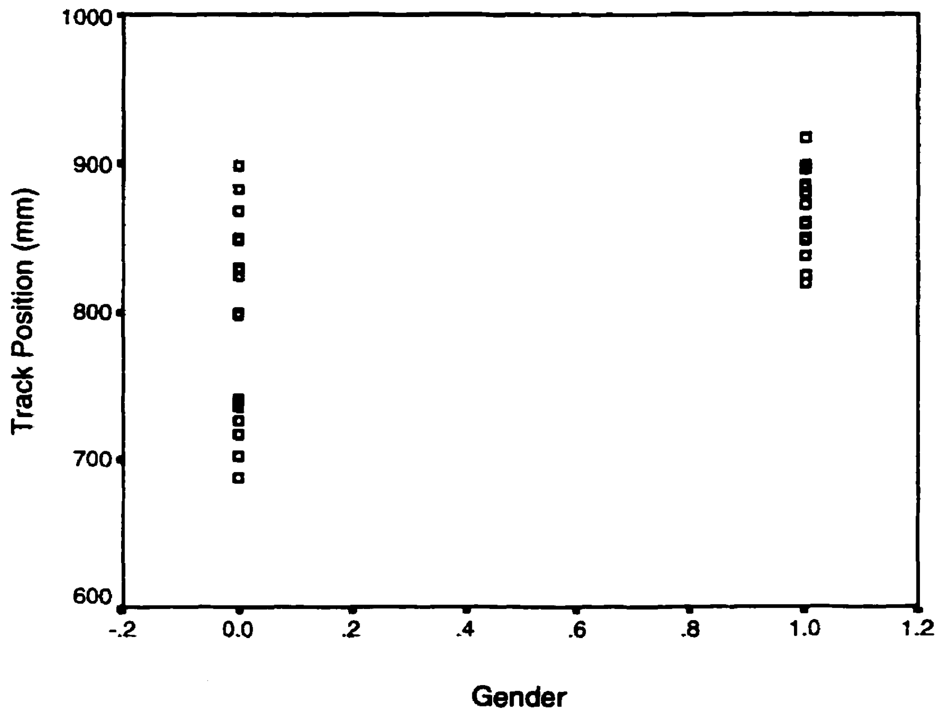


Figure 25: Scatter Plot for Driver Selected Track Position vs. Gender

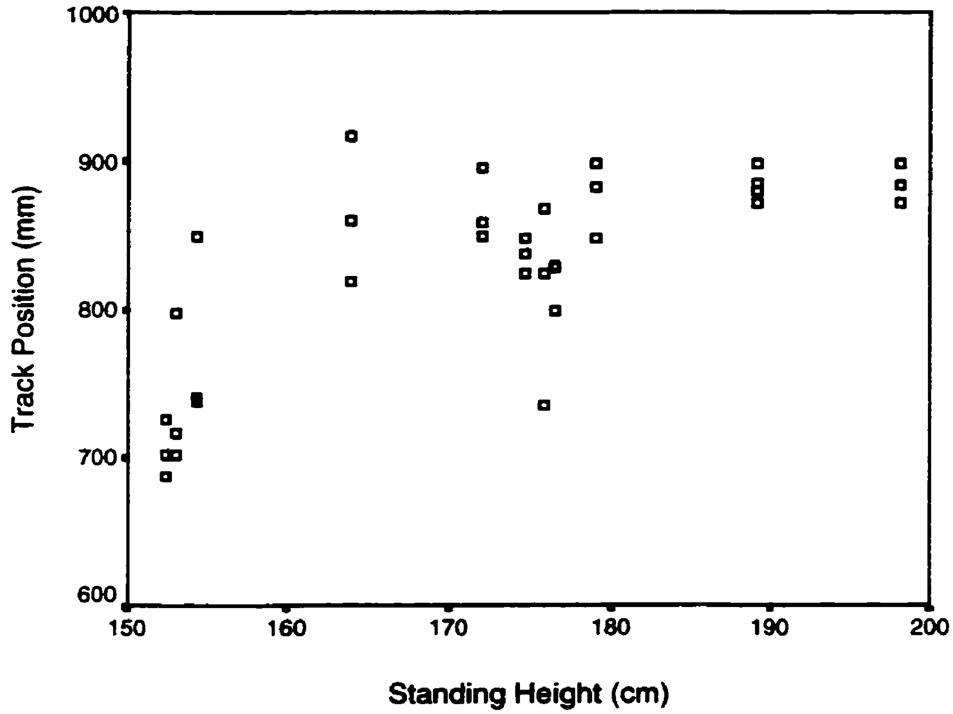


Figure 26: Scatter Plot for Driver Selected Track Position vs. Standing Height

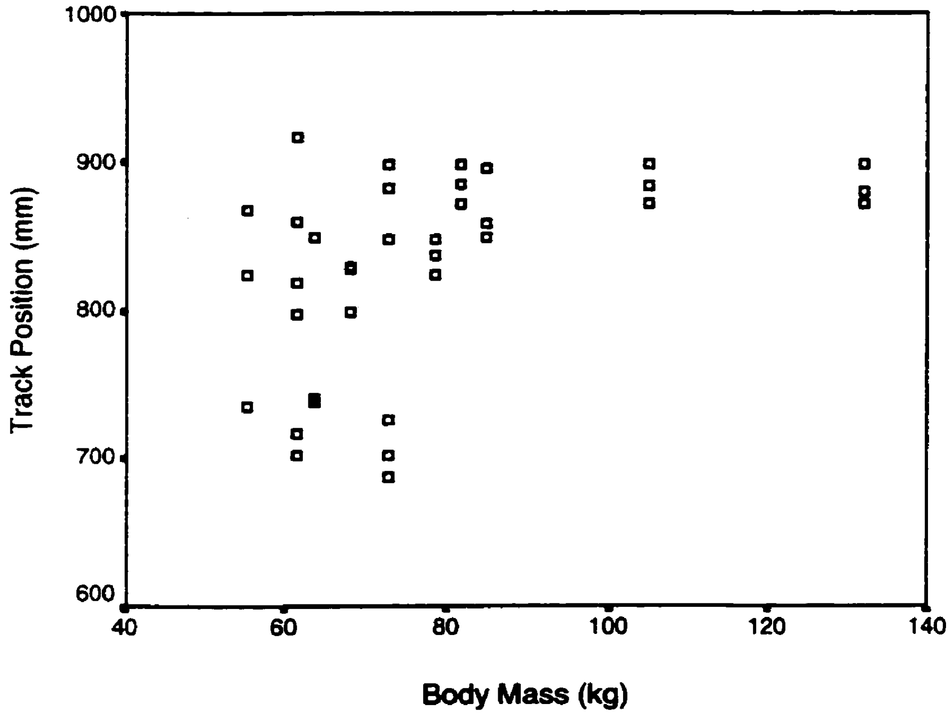


Figure 27: Scatter Plot for Driver Selected Track Position vs. Body Mass

As expected, the relationships represented in Figure 25 – 27 appear to be linear. The correlation coefficients, included in Table 31, indicate that driver selected track position is statistically related to gender, body mass, and standing height.

Table 31: Correlation Matrix for Driver Selected Track Position, Gender, Body Mass, and Standing Height

		Track Position	Gender	Body Mass	Standing Height
Pearson Correlation	Track Position	1.000	0.631 *	0.462 *	0.739 *
	Gender	0.631 *	1.000	0.603 *	0.556 *
	Body Mass	0.462 *	0.603 *	1.000	0.656 *
	Standing Height	0.739 *	0.556 *	0.656 *	1.000
Sig. (2-tailed)	Track Position	.	0.000	0.005	0.000
	Gender	0.000	.	0.000	0.000
	Body Mass	0.005	0.000	.	0.000
	Standing Height	0.000	0.000	0.000	.
N	Track Position	36	36	36	36
	Gender	36	36	36	36
	Body Mass	36	36	36	36
	Standing Height	36	36	36	36

*Correlation is significant at the 0.01 level (2-tailed).

Table 31 also reveals that gender, body mass, and standing height are highly inter-correlated. This is a key finding because it affects the modeling strategy employed. More specifically, a stepwise, multiple linear regression modeling approach was adopted because of the high inter-correlations. In practice, this is the most popular regression procedure. The stepwise selection criteria used for this study were (a) probability-of-F-to-enter = .05 and (b) probability-of-F-to-remove = .10. These are standard regression criteria (SPSS, Inc., 1997).

Seventy-five percent of the total sample was randomly selected and used to develop the model. The remaining 25% of the total sample was used for validation. The performance of the model is summarized in Table 32.

Table 32: Model Summary for Driver Selected Track Position. Predictors: (Constant), Standing Height, and Gender

r	r^2	Adjusted r^2	Std. Error of the Estimate
0.785	0.616	0.592	42.562

The corresponding ANOVA is found in Table 33.

Table 33: Model ANOVA for Driver Selected Track Position. Predictors: (Constant), Standing Height, and Gender

	Sum of Squares	df	Mean Square	F	Sig.
Regression	95805.863	2	47902.932	26.444	0.000
Residual	59779.775	33	1811.508		
Total	155585.639	35			

Table 34 outlines the driver selected track position model coefficients.

Table 34: Model Coefficients for Driver Selected Track Position

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	362.481	98.713		3.672	0.001
Gender	41.858	17.074	0.318	2.452	0.020
Standing Height	2.571	0.594	0.562	4.325	0.000

To summarize, the model has a r^2 of .592 (adjusted for sample size) and a standard error of estimate equal to 42.562. The ability to explain almost 60% of the variance in driver selected track position in the compact car segment, which is undeniably a subjective construct, using only gender and standing height is a promising result - one that should be relatively easy to communicate to the end-consumer. The model is shown in Equation 3.

$$\text{Driver Selected Track Position} = 362.481 + 41.858 * \text{Gender} + 2.571 * \text{Standing Height}$$

Equation 3

It is important to note that the preceding model cannot be advocated until it is validated. To do this, the model expressed in Equation 3 was used to obtain predicted values for the validation sample. Validity was assessed by computing a cross-validated r-value between the predicted and observed values. The result is as follows: $\underline{r}\,(9) = .819$, $\underline{p} = .007$. The scatter plot in Figure 28 graphically depicts the strength of the relationship between the actual and predicted driver selected track position values and, thereby, the validity of the model.

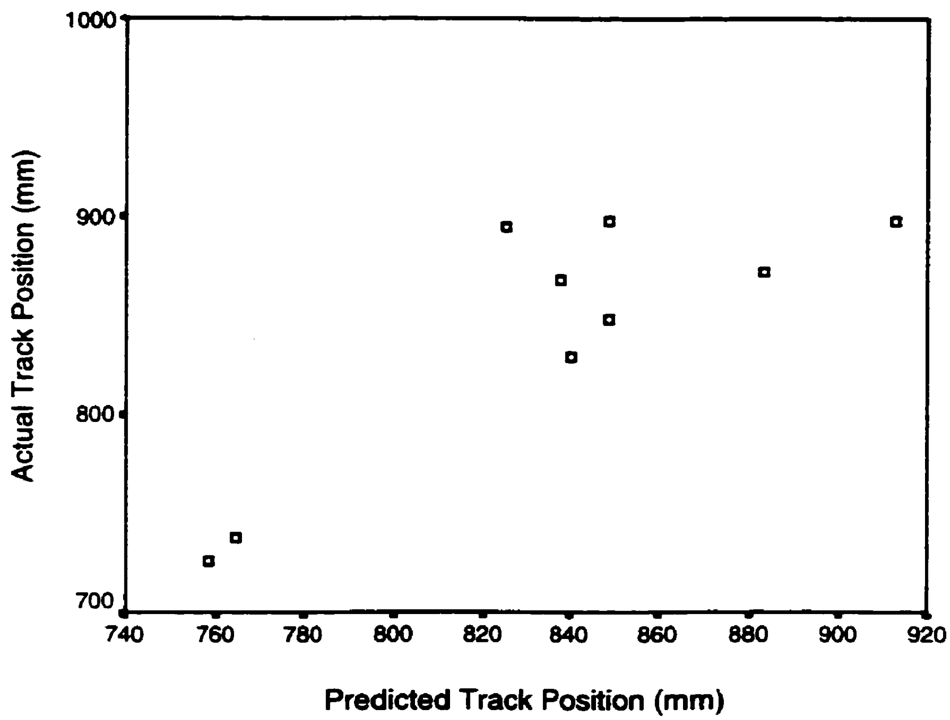


Figure 28: Scatter Plot for Cross Validation of Driver Selected Track Position Model (Actual vs. Predicted)

In order for the consumer to find this information useful, it must be presented in an easy to understand format. Admittedly, recommended track positions, expressed from the design position heel point, do not fall into this category. The fact that all three of the studied seats were equipped with manual tracks makes it possible to translate the recommended track positions to "clicks" from full rear. Consumers should, without too much difficulty, be able to set the track to full rear and then count the clicks required to achieve the recommended starting position. Table 35 is offered as a suggested means of communicating the findings to the consumer. This type of information could easily be included in the owner's manual.

Table 35: Look-Up Table for Recommended Track Position Settings as a Function of Demographic and Anthropometric Characteristics

Gender	Standing Height (cm)	Driver Selected Track Position [from Heel-Point (mm)]	Driver Selected Track Position [clicks from full-rear (mm)] Seat A	Seat B	Seat C
Females	150	748	17	15	12
	155	761	16	14	11
	160	774	14	12	10
	165	787	13	11	9
	170	800	12	10	7
	175	812	10	9	6
Males	165	829	9	7	4
	170	841	8	6	3
	175	854	6	4	2
	180	867	5	3	0
	185	880	4	2	0
	190	893	2	1	0

The following commentary, which is based on (1) watching subjects in this study adjust their seats and (2) certain basic ergonomic principles, is provided to deal with questions concerning how to adjust the automobile seat for comfort.

When the occupant first gets into the automobile seat, the right foot should be placed on the floor behind the brake pedal. The seat should be adjusted fore and aft so that the right knee is slightly bent when the foot is pressed firmly on the floor. Occupants can use the model presented in Equation 3 or the information presented in Table 35 to obtain a sense of how to adjust the track position to achieve this position. The left foot should rest comfortably on the "dead pedal" – an area some vehicle manufacturers provide on the left side of the foot well. If the car has a manual transmission, the occupant needs to be able to completely depress the clutch without pointing the toes. In comfort position this action will take place with minimal rotation of the hip joints. The small of the back should be pressed firmly against the back of the seat and the upper body should be positioned so that the side wings provide as much lateral support as possible.

As far as the seatback angle is concerned, the occupant should sit as reclined as possible while still maintaining proper vision. On a long trip this reduces fatigue. To determine the optimal seatback angle, the occupant should first hold the steering wheel at the 12 o'clock position with one hand. With the shoulders pushed back into the seat, the seatback angle should be adjusted until the elbow is slightly bent. Bent arms provide a biomechanical advantage (as compared to steering with the arms straight). The hands should rest comfortably at the "quarter to three" position or very close to that. As a check, the occupant should, in this position, try to turn the wheel a full 180°. If either hand falls off the wheel during this maneuver, the occupant is too far away. If, on the other hand, the occupant is elbowing himself/herself in the torso, then they are too close

While comfort is important, the unrealized advantage of adjusting the seat in this fashion deals with the ability to control the vehicle (i.e., safe vehicle operation).

It should, however, be stated that no seat can comfortably accommodate an occupant for extended periods of time. Therefore, on long trips, occupants should resist changing the seat adjustments if they begin to experience cramping or discomfort. In other words, once fatigue has set in, no amount of seat adjustment will provide sufficient relief. This is a good signal that the occupant needs to rest. As a rule of thumb, the occupant should plan on stopping to stretch the legs, neck, and back once every two hours. In the long run, this is safer for everyone involved.

4.4 Overall Comfort Model

The seat interface pressure data, found in Appendix D, is based on the pressure profiles found in Appendix E. This data was used to compile the mean, standard deviation, minimum, and maximum for each variable with respect to every seat. This data is included in Table 36.

Table 36: Descriptive Statistics for Seat Interface Pressure Measures

SEAT		CCA (cm^2)	CTF (N)	CCF (g/cm^2)	CPP (g/cm^2)	BCA (cm^2)	BTF (N)	BCF (g/cm^2)	BPP (g/cm^2)
A	Mean	1716.81	597.8	26	111.6	1317.93	273.1	27	71.5
	N	12	12	12	12	12	12	12	12
	STD	112.93	160.3	19	28.1	191.22	73.7	16	28.4
	Min	1584.51	376.5	0	71.1	1085.93	191.6	5	46.2
	Max	1967.48	1010.2	68	160.0	1652.64	421.6	51	135.0
B	Mean	1699.44	588.3	26	124.0	1337.90	240.2	19	67.5
	N	12	12	12	12	12	12	12	12
	STD	122.42	193.9	12	49.5	247.55	73.7	11	17.1
	Min	1493.67	366.9	0	62.7	989.93	137.4	3	43.8
	Max	1964.38	1065.5	43	247.0	1896.25	362.7	40	103.0
C	Mean	1745.80	696.7	24	157.6	1341.68	277.1	18	115.4
	N	12	12	12	12	12	12	12	12
	STD	111.90	172.1	16	74.7	280.54	108.1	12	90.6
	Min	1622.71	537.2	3	63.2	849.55	140.4	0	42.8
	Max	2001.54	1185.5	51	349.0	1907.61	517.8	40	291.0
D	Mean	1629.85	564.5	32	109.5	1219.01	250.0	30	74.7
	N	12	12	12	12	12	12	12	12
	STD	118.93	154.8	16	30.9	183.45	88.4	12	21.4
	Min	1493.67	358.9	6	60.5	1005.42	125.6	7	46.0
	Max	1916.90	957.8	56	173.0	1711.48	451.0	46	106.0
E	Mean	1724.81	578.6	23	89.1	1358.27	321.7	39	74.9
	N	12	12	12	12	12	12	12	12
	STD	117.13	149.5	11	27.8	253.71	115.6	15	17.4
	Min	1493.67	424.0	4	54.1	952.77	153.8	13	47.7
	Max	1947.87	970.0	36	159.0	1977.80	557.0	61	117.0
Total	Mean	1703.34	605.2	26	118.4	1314.96	272.4	27	80.8
	N	60	60	60	60	60	60	60	60
	STD	119.58	168.0	15	49.8	231.73	94.7	15	46.8
	Min	1493.67	358.9	0	54.1	849.55	125.6	0	42.8
	Max	2001.54	1185.5	68	349.0	1977.80	557.0	61	291.0

A one-way ANOVA was performed to determine if there was a difference between the different seats with regards to pressure characteristics. The results are shown in Table 37.

Table 37: One-Way ANOVA for Seat Interface Pressure Measure Differences between Seats

		Sum of Squares	df	Mean Square	F	Sig.
CCA	Between Seats	94346.798	4	23586.699	1.731	0.156
	Within Seats	749382.925	55	13625.144		
	Total	843729.723	59			
CTF	Between Seats	133067.292	4	33266.823	1.195	0.323
	Within Seats	1531350.961	55	27842.745		
	Total	1664418.253	59			
CCF	Between Seats	554.233	4	138.558	0.604	0.661
	Within Seats	12613.500	55	229.336		
	Total	13167.733	59			
CPP	Between Seats	30635.136	4	7658.784	3.632	0.011
	Within Seats	115966.372	55	2108.479		
	Total	146601.507	59			
BCA	Between Seats	147976.804	4	36994.201	0.674	0.613
	Within Seats	3020261.389	55	54913.843		
	Total	3168238.193	59			
BTF	Between Seats	47893.236	4	11973.309	1.369	0.257
	Within Seats	480967.674	55	8744.867		
	Total	528860.910	59			
BCF	Between Seats	3436.433	4	859.108	4.930	0.002
	Within Seats	9584.500	55	174.264		
	Total	13020.933	59			
BPP	Between Seats	18360.978	4	4590.244	2.278	0.072
	Within Seats	110814.024	55	2014.800		
	Total	129175.002	59			

Only CPP and BCF can be used to quantitatively distinguish between seats. That is, these pressure variables resulted in a statistically significant difference (at the .05 level) between seats in this study. Dunnett's C Test (Table 38) was used to reveal that, in terms of CPP, Seat C (mean CPP = 157.6 g/cm^2) is different than Seat E (mean CPP = 89.1 g/cm^2). Similarly, considering BCF, Seat B (mean BCF = 19 g/cm^2) and Seat C (mean BCF = 18 g/cm^2) are different than Seat E (mean BCF = 39 g/cm^2). Once again, Dunnett's C Test is appropriate because the variances between the seats are unequal (as indicated in Table 36).

Table 38: Dunnett's C Test for Differences in Cushion Peak Pressure and Seatback Load at the Center of Force

Dependent Variable	(I) SEAT	(J) SEAT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
CPP	A	B	-12.442	18.746	0.000	-65.595	40.712
		C	-46.017	18.746	0.000	-120.489	28.456
		D	2.083	18.746	0.000	-36.902	41.068
		E	22.492	18.746	0.000	-14.424	59.407
	B	A	12.442	18.746	0.000	-40.712	65.595
		C	-33.575	18.746	0.000	-117.209	50.059
		D	14.525	18.746	0.000	-39.957	69.007
		E	34.933	18.746	0.000	-18.087	87.954
	C	A	46.017	18.746	0.000	-28.456	120.489
		B	33.575	18.746	0.000	-50.059	117.209
		D	48.100	18.746	0.000	-27.326	123.526
		E	-68.508 *	18.746	0.000	-5.870	142.886
	D	A	-2.083	18.746	0.000	-41.068	36.902
		B	-14.525	18.746	0.000	-69.007	39.957
		C	-48.100	18.746	0.000	-123.526	27.326
		E	20.408	18.746	0.000	-18.396	59.212
	E	A	-22.492	18.746	0.000	-59.407	14.424
		B	-34.933	18.746	0.000	-87.954	18.087
		C	-68.508 *	18.746	0.000	-142.886	5.870
		D	-20.408	18.746	0.000	-59.212	18.396
BCF	A	B	7.917	5.389	0.000	-9.808	25.641
		C	9.083	5.389	0.000	-9.574	27.740
		D	-3.167	5.389	0.000	-21.616	15.283
		E	-11.500	5.389	0.000	-31.537	8.537
	B	A	-7.917	5.389	0.000	-25.641	9.808
		C	1.167	5.389	0.000	-14.080	16.414
		D	-11.083	5.389	0.000	-26.075	3.909
		E	-19.417 *	5.389	0.000	-36.325	-2.509
	C	A	-9.083	5.389	0.000	-27.740	9.574
		B	-1.167	5.389	0.000	-16.414	14.080
		D	-12.250	5.389	0.000	-28.333	3.833
		E	-20.583 *	5.389	0.000	-38.466	-2.701
	D	A	3.167	5.389	0.000	-15.283	21.616
		B	11.083	5.389	0.000	-3.909	26.075
		C	12.250	5.389	0.000	-3.833	28.333
		E	-8.333	5.389	0.000	-25.999	9.333
	E	A	11.500	5.389	0.000	-8.537	31.537
		B	19.417 *	5.389	0.000	2.509	36.325
		C	20.583 *	5.389	0.000	2.701	38.466
		D	8.333	5.389	0.000	-9.333	25.999

*The mean difference is significant at the .05 level.

A matrix of correlation coefficients for the seat interface pressure variables is shown in Table 39.

Table 39: Correlation Matrix for Seat Interface Pressure Measures

		CCA	CTF	CCF	CPP	BCA	BTF	BCF	BPP
Pearson Correlation	CCA	1.000	0.778 **	0.236	0.238	0.705 **	0.553 **	-0.088	0.097
	CTF	0.778 **	1.000	0.478 **	0.579 **	0.807 **	0.698 **	-0.126	0.368 **
	CCF	0.236	0.478 **	1.000	0.324 *	0.380 **	0.342 **	-0.031	0.099
	CPP	0.238	0.579 **	0.324 *	1.000	0.402 **	0.356 **	-0.304 *	0.661 **
	BCA	0.705 **	0.807 **	0.380 **	0.402 **	1.000	0.879 **	-0.121	0.254 *
	BTF	0.553 **	0.698 **	0.342 **	0.356 **	0.879 **	1.000	0.192	0.382 **
	BCF	-0.088	-0.126	-0.031	-0.304 *	-0.121	0.192	1.000	-0.060
	BPP	0.097	0.368 **	0.099	0.661 **	0.254 *	0.382 **	-0.060	1.000
Sig. (2-tailed)	CCA	.	0.000	0.069	0.067	0.000	0.000	0.505	0.462
	CTF	0.000	.	0.000	0.000	0.000	0.000	0.336	0.004
	CCF	0.069	0.000	.	0.012	0.003	0.007	0.817	0.450
	CPP	0.067	0.000	0.012	.	0.001	0.005	0.018	0.000
	BCA	0.000	0.000	0.003	0.001	.	0.000	0.359	0.050
	BTF	0.000	0.000	0.007	0.005	0.000	.	0.142	0.003
	BCF	0.505	0.336	0.817	0.018	0.359	0.142	.	0.649
	BPP	0.462	0.004	0.450	0.000	0.050	0.003	0.649	.
N	CCA	60	60	60	60	60	60	60	60
	CTF	60	60	60	60	60	60	60	60
	CCF	60	60	60	60	60	60	60	60
	CPP	60	60	60	60	60	60	60	60
	BCA	60	60	60	60	60	60	60	60
	BTF	60	60	60	60	60	60	60	60
	BCF	60	60	60	60	60	60	60	60
	BPP	60	60	60	60	60	60	60	60

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Many of the relationships outlined in Table 39 proved to be statistically significant at the .05 level. This affects the primary deliverable of this research work, which is to establish a relationship, expressed via an equation, for predicting perceptions of comfort from objective measures. The number of pressure variables and the fact that they are highly correlated calls for the use of a stepwise selection procedure. This procedure (previously discussed in the context of driver selected track position model development) is used to determine just which set of predictor variables to include in a multiple regression model.

In addition to predicting the outcome variable for a new sample of data, the model will (1) assess how well subjective perceptions of comfort can be explained by knowing the value of a set of predictor variables and (2) identify which subset from many measures is most effective for estimating subjective perceptions of comfort. This should help seat system design teams develop more comfortable automobile seats.

Prior to model development, the relationship between each of the 12 predictor variables (i.e., three anthropometric/demographic variables, one appearance rating variable, and eight seat interface pressure variables) and the overall comfort index (dependent variable representing subjective perceptions of comfort) was examined. Scatter plots (Figure 29 - 40) were used for this purpose.

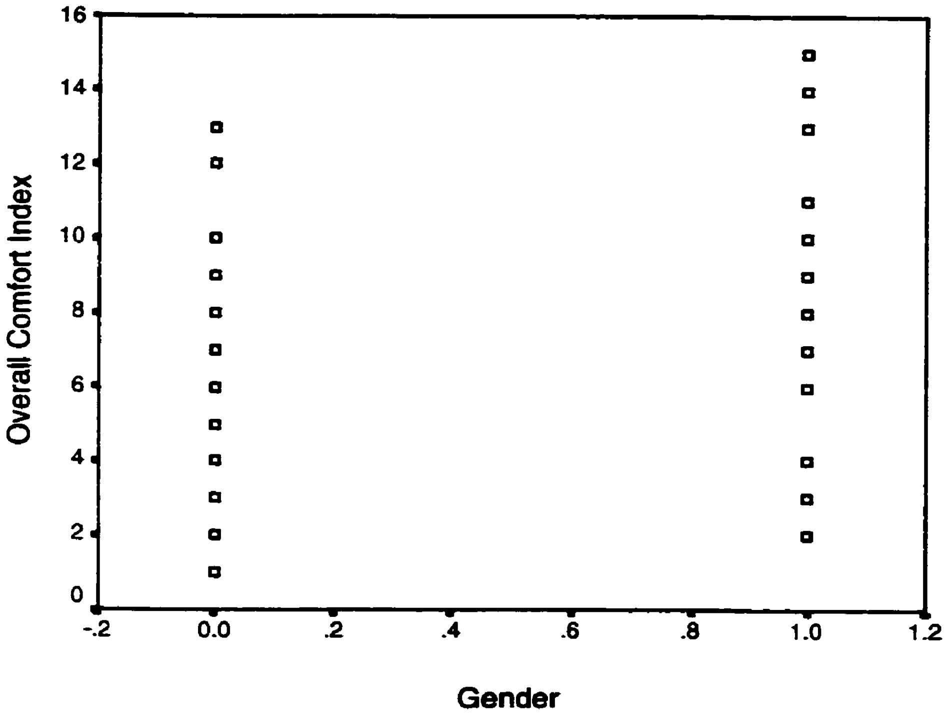


Figure 29: Scatter Plot of Overall Comfort Index vs. Gender

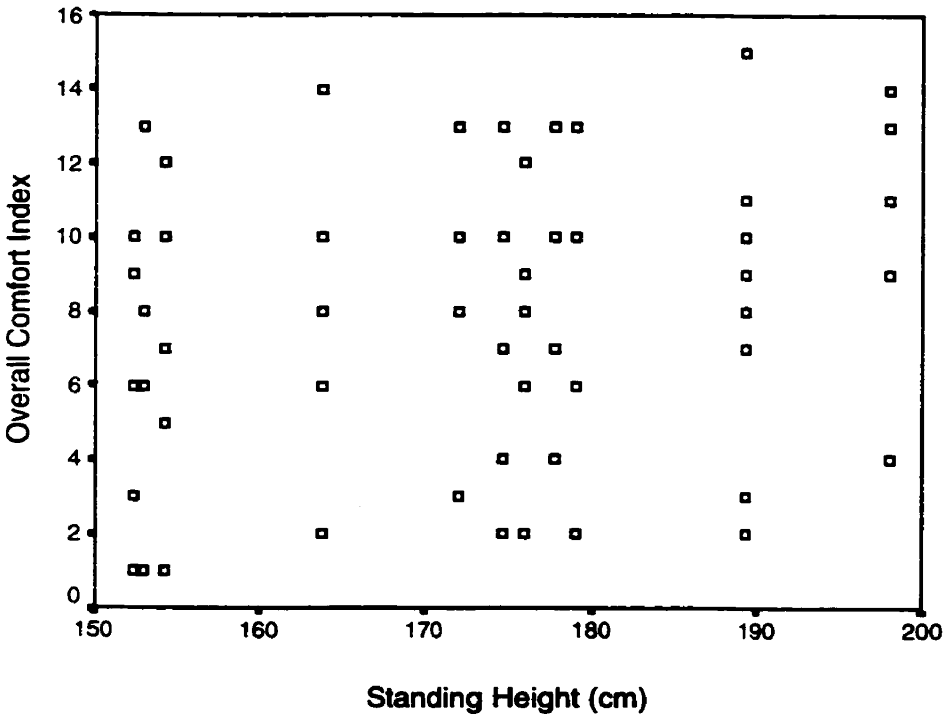


Figure 30: Scatter Plot of Overall Comfort Index vs. Standing Height

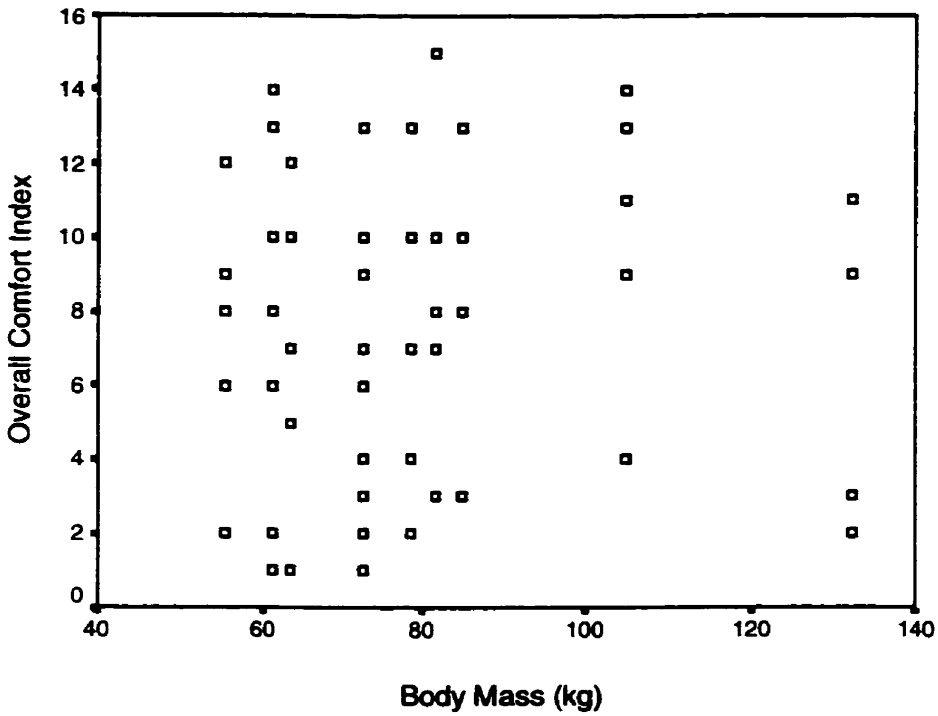


Figure 31: Scatter Plot of Overall Comfort Index vs. Body Mass

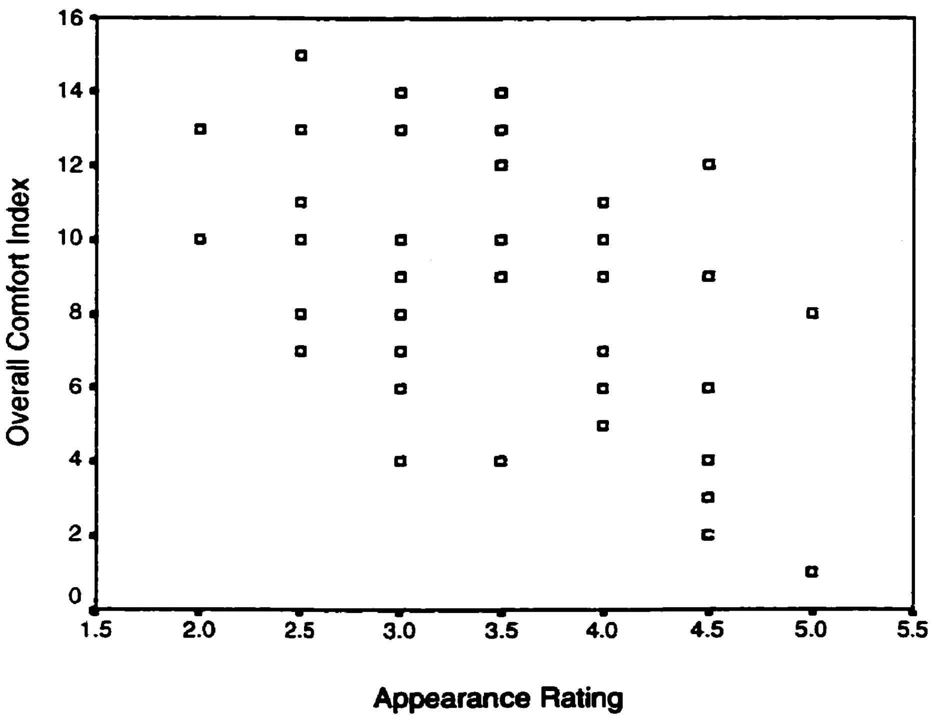


Figure 32: Scatter Plot of Overall Comfort Index vs. Appearance Rating

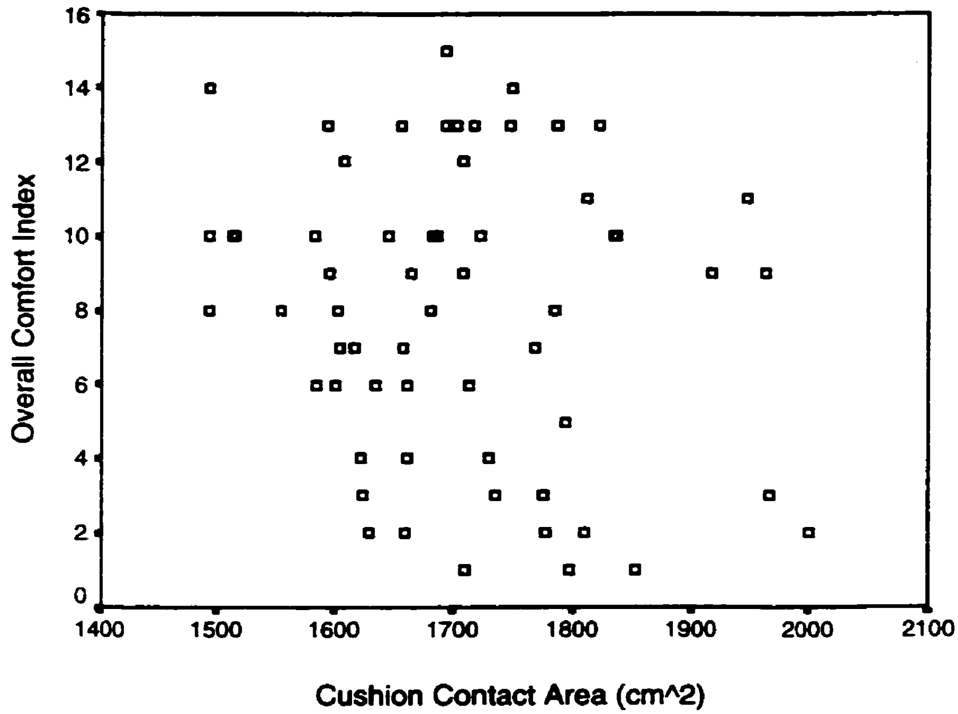


Figure 33: Scatter Plot of Overall Comfort Index vs. Cushion Contact Area

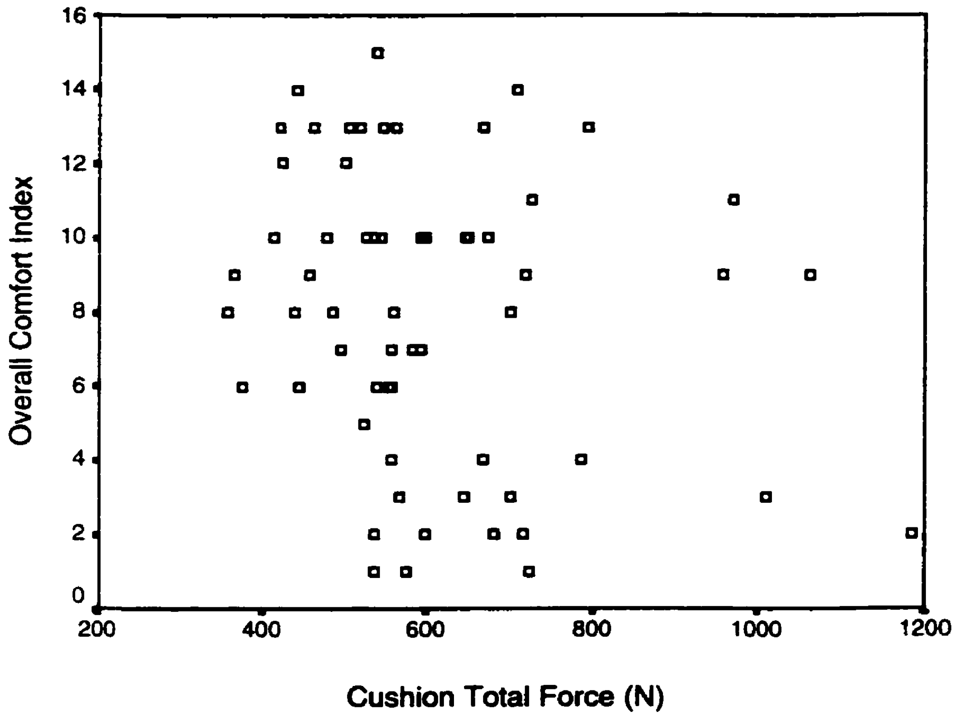


Figure 34: Scatter Plot of Overall Comfort Index vs. Cushion Total Force

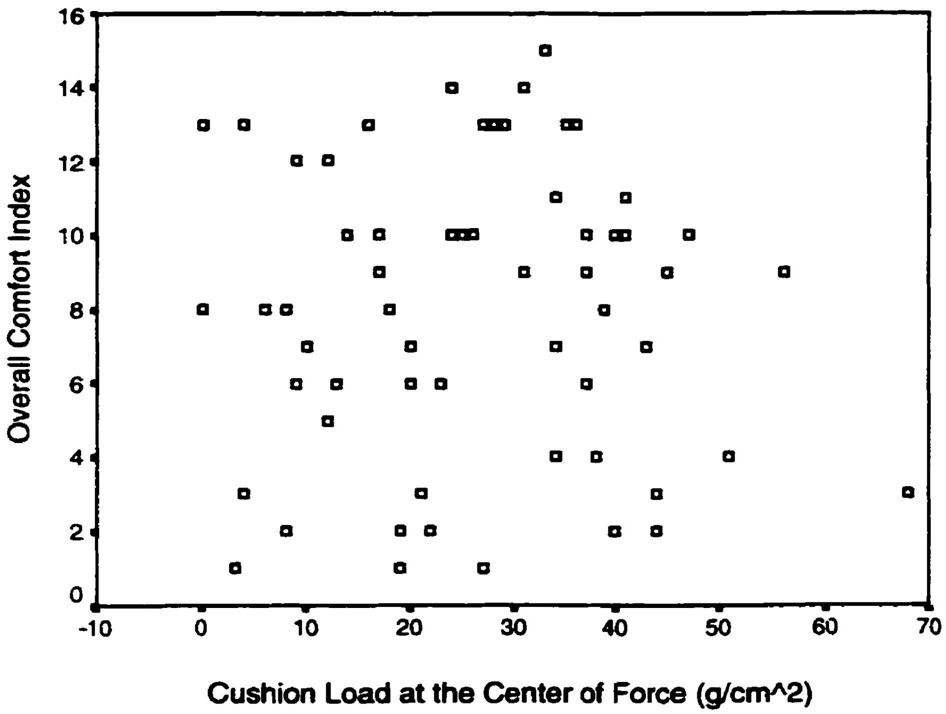


Figure 35: Scatter Plot of Overall Comfort Index vs. Cushion Load at the Center of Force

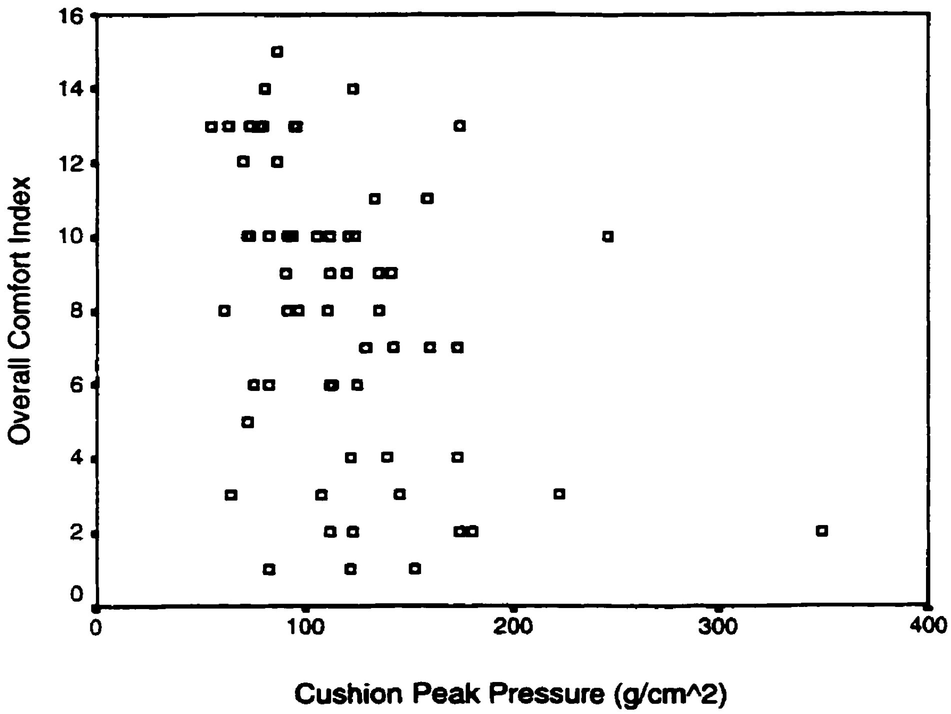


Figure 36: Scatter Plot of Overall Comfort Index vs. Cushion Peak Pressure

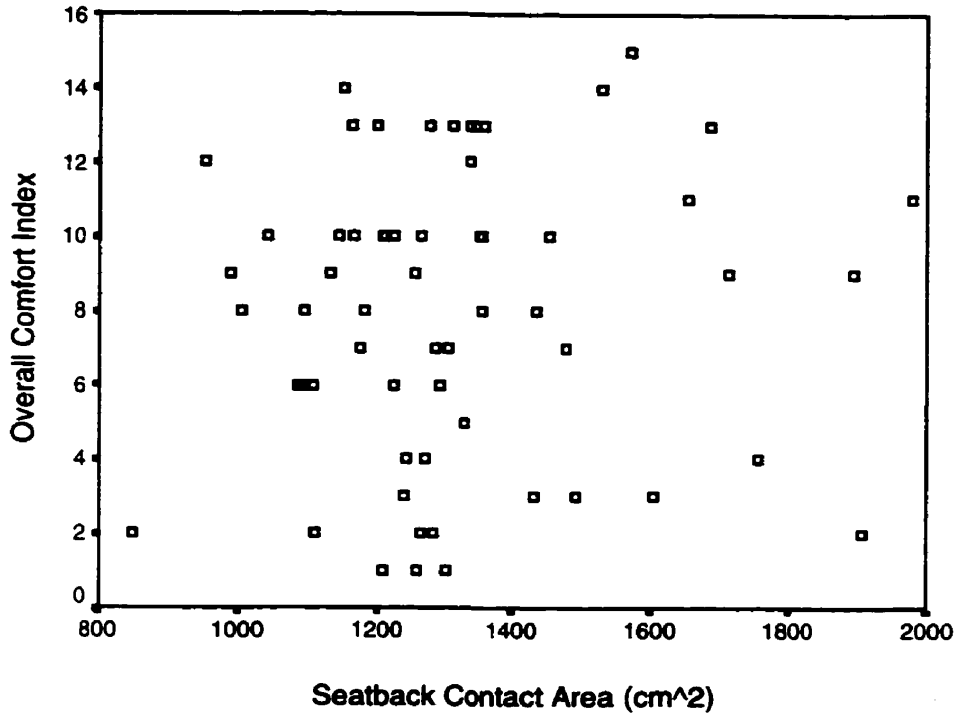


Figure 37: Scatter Plot of Overall Comfort Index vs. Seatback Contact Area

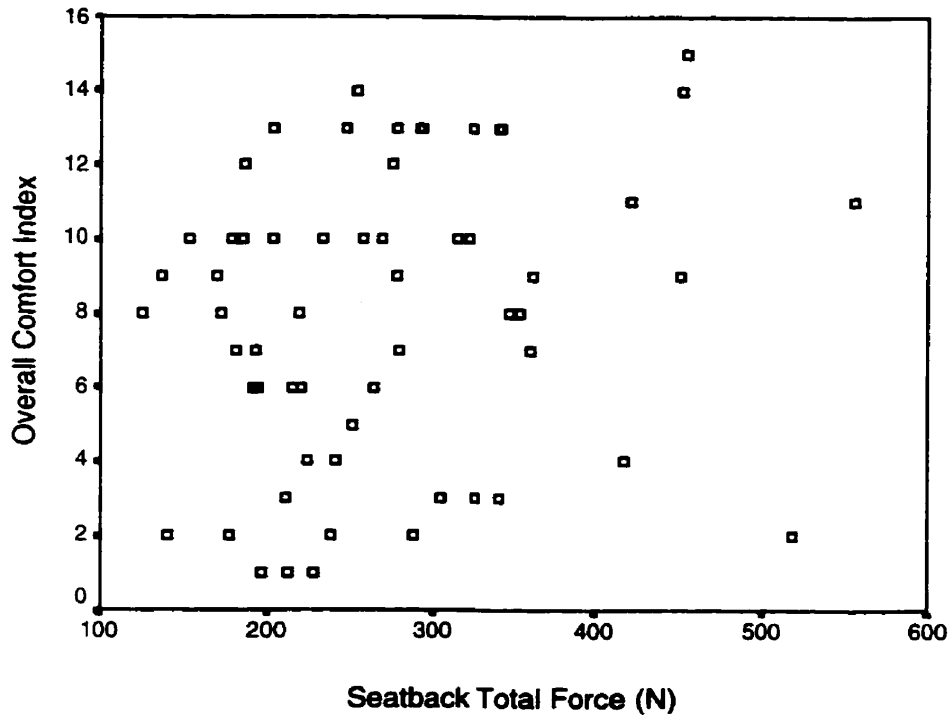


Figure 38: Scatter Plot of Overall Comfort Index vs. Seatback Total Force

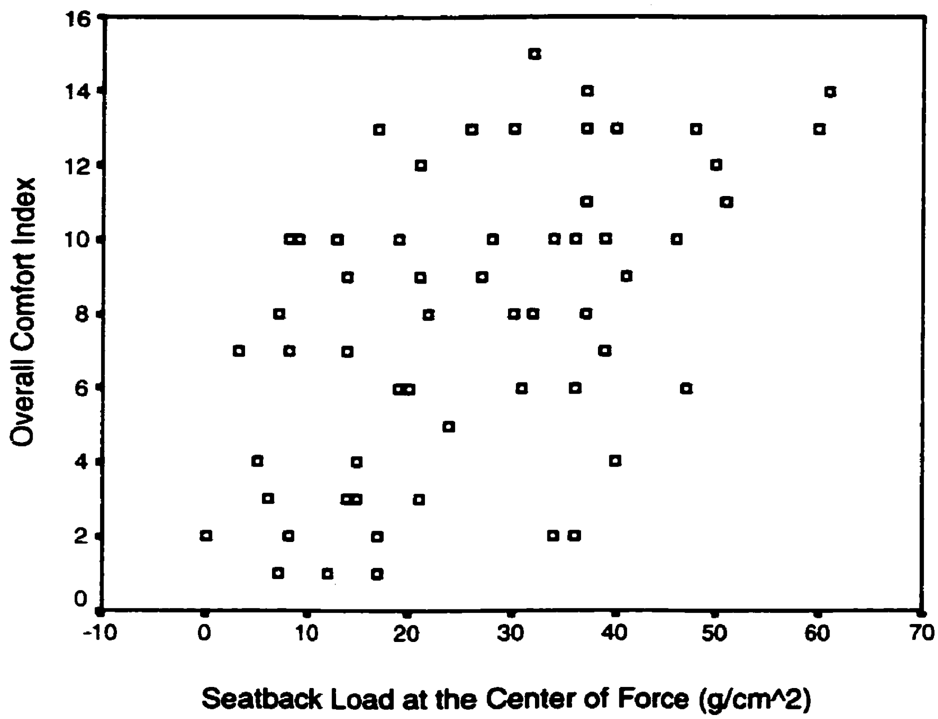


Figure 39: Scatter Plot of Overall Comfort Index vs. Seatback Load at the Center of Force

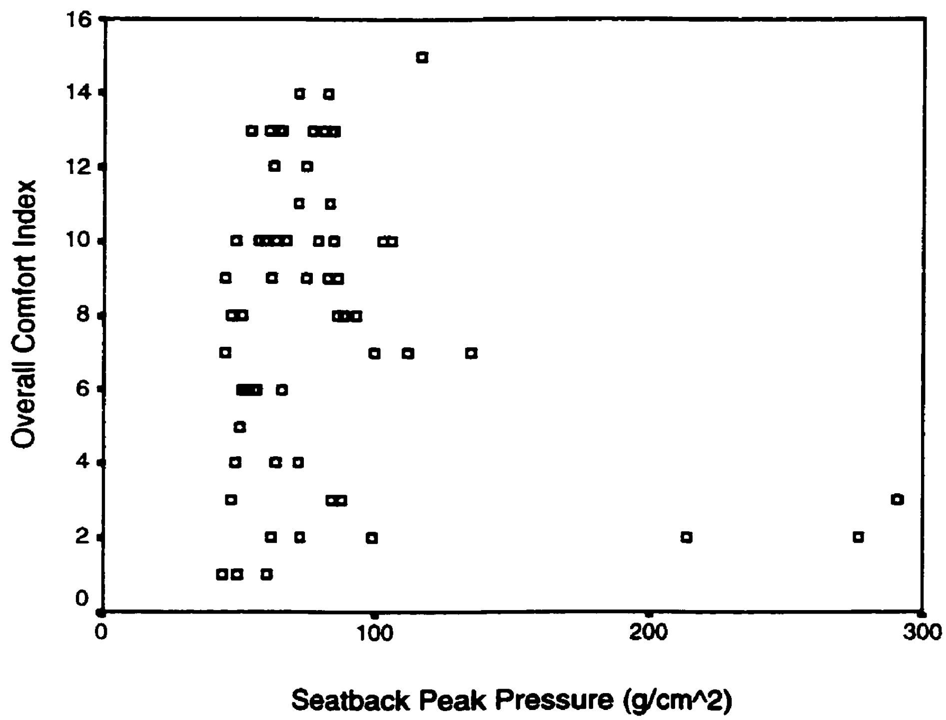


Figure 40: Scatter Plot of Overall Comfort Index vs. Seatback Peak Pressure

One might expect the predictor variables, particularly those dealing with seat interface pressure (Figure 33 to Figure 40), to have a quadratic relationship with the dependent variable. That is, one would think that there was an optimal amount of CCA (for example) and that too much or too little CCA would be equally detrimental. The scatter plots did not reveal this to be the case. The same was true for the factors dealing with demographics (Figure 29), anthropometry (Figure 30 to Figure 31), and appearance rating (Figure 32). For this reason, a linear modeling approach was adopted.

Table 40 shows that AR, BCF, and CPP resulted in the strongest linear relationships with the overall comfort index. In fact, these relationships were statistically significant at the .05 level. Although correlation does not imply causality, automobile seat design studios would, almost definitely, be interested in knowing that appearance is related to comfort.

Table 40: Relationship Between Predictor Variables and Overall Comfort Index

		Overall Comfort Index
Pearson Correlation	Overall Comfort Index	1.000
	Gender	0.076
	Standing Height	0.163
	Body Mass	0.031
	Appearance Rating	-0.645 **
	Cushion Contact Area	-0.181
	Cushion Total Force	-0.219
	Cushion Load at the Center of Force	-0.032
	Cushion Peak Pressure	-0.381 **
	Seatback Contact Area	0.062
	Seatback Total Force	0.203
	Seatback Load at the Center of Force	0.505 **
	Seatback Peak Pressure	-0.201
Sig. (2-tailed)	Overall Comfort Index	.
	Gender	0.562
	Standing Height	0.213
	Body Mass	0.817
	Appearance Rating	0.000
	Cushion Contact Area	0.166
	Cushion Total Force	0.092
	Cushion Load at the Center of Force	0.808
	Cushion Peak Pressure	0.003
	Seatback Contact Area	0.635
	Seatback Total Force	0.119
	Seatback Load at the Center of Force	0.000
	Seatback Peak Pressure	0.124
N	Overall Comfort Index	60
	Gender	60
	Standing Height	60
	Body Mass	60
	Appearance Rating	60
	Cushion Contact Area	60
	Cushion Total Force	60
	Cushion Load at the Center of Force	60
	Cushion Peak Pressure	60
	Seatback Contact Area	60
	Seatback Total Force	60
	Seatback Load at the Center of Force	60
	Seatback Peak Pressure	60

**Correlation is significant at the 0.01 level (2-tailed).

Just as with the driver selected track position model, 75% of the total sample was randomly selected and used to develop the overall comfort index model. The remaining 25% of the data was used for validation. The model summary is shown in Table 41.

Table 41: Model Summary for Overall Comfort Index

Model	r	r^2	Adjusted r^2	Std. Error of the Estimate
1	0.621[a]	0.385	0.371	3.175
2	0.729[b]	0.531	0.509	2.806
3	0.762[c]	0.581	0.551	2.683
4	0.790[d]	0.623	0.586	2.576
5	0.817[e]	0.667	0.625	2.453
6	0.844[f]	0.713	0.668	2.308
7	0.839[g]	0.704	0.666	2.313
8	0.830[h]	0.688	0.657	2.344

[a]Predictors: (Constant), AR
[b]Predictors: (Constant), AR, BCF
[c]Predictors: (Constant), AR, BCF, CPP
[d]Predictors: (Constant), AR, BCF, CPP, BTF
[e]Predictors: (Constant), AR, BCF, CPP, BTF, CTF
[f]Predictors: (Constant), AR, BCF, CPP, BTF, CTF, WT
[g]Predictors: (Constant), AR, BCF, BTF, CTF, WT
[h]Predictors: (Constant), AR, BCF, CTF, WT

The ANOVA for the models summarized in Table 41 are outlined in Table 42.

Table 42: Model ANOVA for Overall Comfort Index

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	271.796	1	271.796	26.966	0.000[a]
	Residual	433.404	43	10.079		
	Total	705.200	44			
2	Regression	374.441	2	187.220	23.773	0.000[b]
	Residual	330.759	42	7.875		
	Total	705.200	44			
3	Regression	409.955	3	136.652	18.977	0.000[c]
	Residual	295.245	41	7.201		
	Total	705.200	44			
4	Regression	439.680	4	109.920	16.559	0.000[d]
	Residual	265.520	40	6.638		
	Total	705.200	44			
5	Regression	470.505	5	94.101	15.637	0.000[e]
	Residual	234.695	39	6.018		
	Total	705.200	44			
6	Regression	502.752	6	83.792	15.728	0.000[f]
	Residual	202.448	38	5.328		
	Total	705.200	44			
7	Regression	496.598	5	99.320	18.569	0.000[g]
	Residual	208.602	39	5.349		
	Total	705.200	44			
8	Regression	485.470	4	121.367	22.094	0.000[h]
	Residual	219.730	40	5.493		
	Total	705.200	44			

[a]Predictors: (Constant), AR
[b]Predictors: (Constant), AR, BCF
[c]Predictors: (Constant), AR, BCF, CPP
[d]Predictors: (Constant), AR, BCF, CPP, BTF
[e]Predictors: (Constant), AR, BCF, CPP, BTF, CTF
[f]Predictors: (Constant), AR, BCF, CPP, BTF, CTF, WT
[g]Predictors: (Constant), AR, BCF, BTF, CTF, WT
[h]Predictors: (Constant), AR, BCF, CTF, WT

Table 43 outlines the coefficients for all the possible models.

Table 43: Model Coefficients for Overall Comfort Index

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	19.044	2.216		8.592	0.000
	AR	-3.057	0.589	-0.621	-5.193	0.000
2	(Constant)	14.828	2.281		6.501	0.000
	AR	-2.671	0.531	-0.542	-5.027	0.000
	BCF	0.101	0.028	0.389	3.610	0.001
3	(Constant)	17.800	2.559		6.957	0.000
	AR	-2.740	0.509	-0.556	-5.383	0.000
	BCF	0.081	0.028	0.313	2.881	0.006
	CPP	-0.018	0.008	-0.237	-2.221	0.032
4	(Constant)	15.545	2.678		5.805	0.000
	AR	-2.490	0.503	-0.506	-4.953	0.000
	BCF	0.068	0.028	0.263	2.458	0.018
	CPP	-0.026	0.009	-0.338	-2.993	0.005
	BTF	0.010	0.005	0.235	2.116	0.041
5	(Constant)	16.532	2.587		6.391	0.000
	AR	-2.313	0.485	-0.470	-4.768	0.000
	BCF	0.061	0.027	0.236	2.300	0.027
	CPP	-0.016	0.009	-0.207	-1.697	0.098
	BTF	0.019	0.006	0.477	3.172	0.003
	CTF	-0.009	0.004	-0.375	-2.263	0.029
6	(Constant)	13.749	2.684		5.123	0.000
	AR	-2.038	0.470	-0.414	-4.336	0.000
	BCF	0.062	0.025	0.239	2.472	0.018
	CPP	-0.010	0.009	-0.128	-1.075	0.289
	BTF	0.010	0.007	0.256	1.531	0.134
	CTF	-0.020	0.006	-0.862	-3.422	0.002
	WT	0.133	0.054	0.669	2.460	0.019
7	(Constant)	13.043	2.608		5.002	0.000
	AR	-1.988	0.469	-0.404	-4.243	0.000
	BCF	0.069	0.024	0.266	2.852	0.007
	BTF	0.010	0.007	0.241	1.442	0.157
	CTF	-0.024	0.005	-0.995	-4.536	0.000
	WT	0.149	0.052	0.748	2.849	0.007
8	(Constant)	12.713	2.632		4.830	0.000
	AR	-2.062	0.472	-0.419	-4.370	0.000
	BCF	0.076	0.024	0.292	3.146	0.003
	CTF	-0.024	0.005	-0.998	-4.487	0.000
	WT	0.189	0.045	0.950	4.223	0.000

Automatic modeling procedures cannot do all the work. They should be used as tools to determine roughly the number of predictors needed. It is possible to find several subsets that perform equally well. Then knowledge of the subject matter, how accurately individual variables are measured, and what a variable communicates may guide selection of the model to report. From this analysis, Model #6 (refer to Table 43), which has an adjusted r^2 of 0.668, a standard error of 2.3082, and an F value of 15.728 ($p = .000$), was determined to be the best. The model is presented in Equation 4.

$$\text{Overall Comfort Index} = 13.749 - 2.038\ AR + 0.0620\ BCF - 0.010\ CPP + 0.010\ BTF - 0.020\ CTF + 0.133\ WT$$

Equation 4

Using the validation sample (25% of the total sample set), a predicted overall comfort index was computed and plotted against the actual overall comfort index (Figure 41).

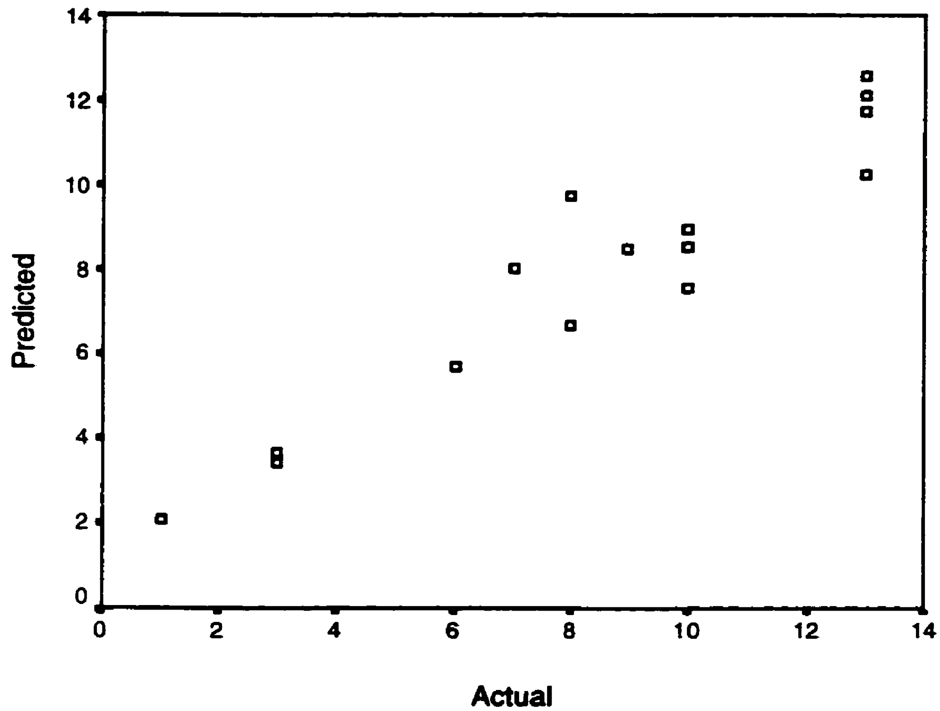


Figure 41: Scatter Plot for Cross Validation of Overall Comfort Index Model (Actual vs. Predicted)

A cross-validated r-value was then computed between the actual and predicted overall comfort index. The result is as follows: $r\,(15) = 0.952$, $p = .000$. The model must, therefore, be considered valid.

Using this model it can be said that a comfortable compact car seat has low BCF and BTF and high CPP and CTF. The model also demonstrates that measures of CCA, CCF, BCA, and BPP do not impact perceptions of comfort. This information is important because it allows seat system design teams to (1) focus on only those seat interface pressure parameters that are related to comfort and (2) establish human criteria for seat interface pressure. The human criteria outlined in Table 44 are based on the mean seat interface pressure values for Seat C (presented in Table 36). Recall that Seat C was, according to the overall comfort index, the most highly rated.

Table 44: Human Criteria for Important Seat Interface Pressure Measures

Seat Interface Pressure Measure	Human Criterion
Seatback Load at the Center of Force (BCF)	< 18 g/cm^2
Seatback Total Force (BTF)	< 277.1 N
Cushion Peak Pressure (CPP)	> 157.6 g/cm^2
Cushion Total Force (CTF)	> 696.7 N

4.5 Seat Contour and Geometry

Up until this point, this manuscript was focused on relating various objective measures (primarily seat interface pressure) to subjective perceptions of comfort. The results, while promising, do not really provide automobile seat designers with concrete recommendations. For this work to make a truly important contribution, it is essential to understand how to impact the objective measures related to comfort. To this end, an approach to seat geometry and contour optimization was adopted that will yield seat comfort design guidelines.

The first step was to overlay the raw scan data (for each seat) over estimated H-Point. In this way the differences between the seats became more apparent. This was done in Figure 42 to Figure 56.

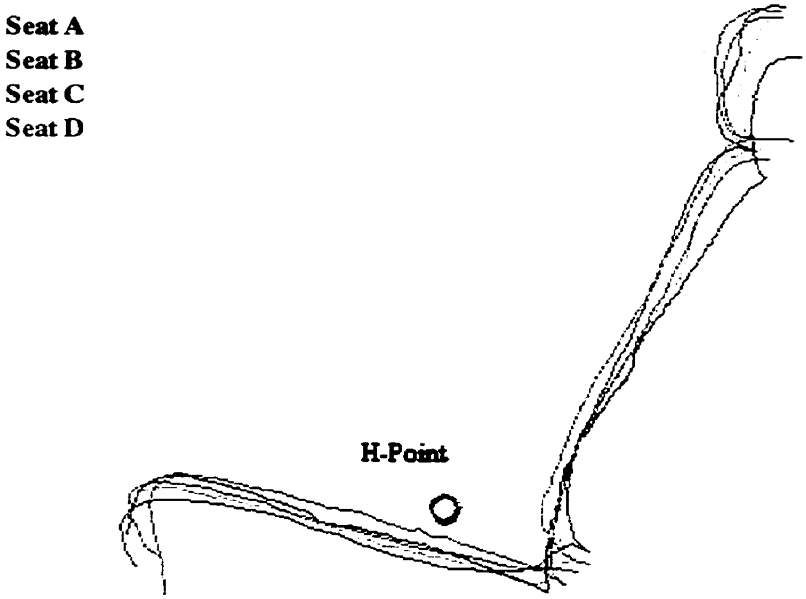


Figure 42: Centerline Section

Figure 43: Cushion Section through H-Point

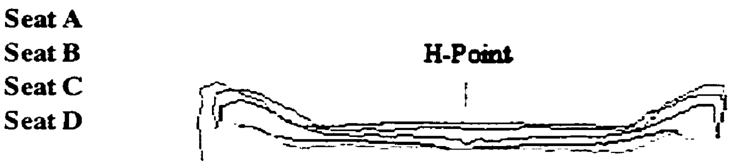


Figure 44: Cushion Section +50 mm from H-Point

Figure 45: Cushion Section +100 mm from H-Point

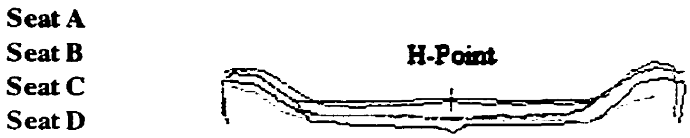


Figure 46: Cushion Section +150 mm from H-Point

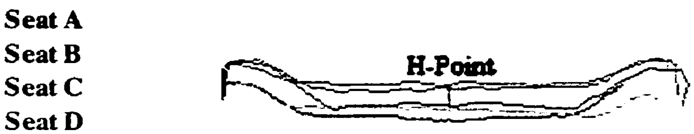


Figure 47: Cushion Section +200 mm from H-Point

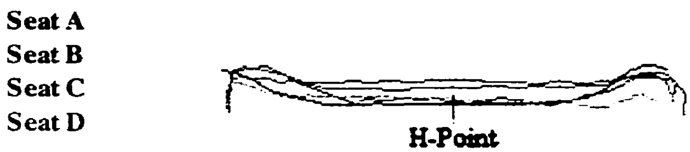


Figure 48: Cushion Section +250 mm from H-Point

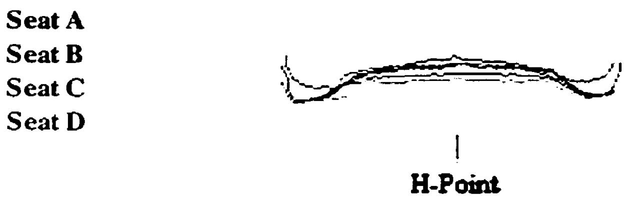


Figure 49: Seatback Section through H-Point

Figure 50: Seatback Section +50 mm from H-Point

Figure 51: Seatback Section +100 mm from H-Point

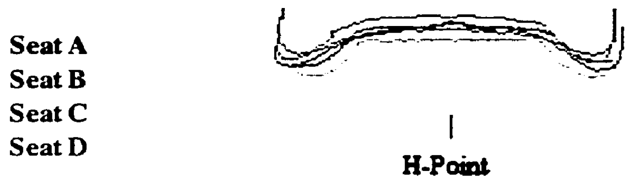


Figure 52: Seatback Section +150 mm from H-Point

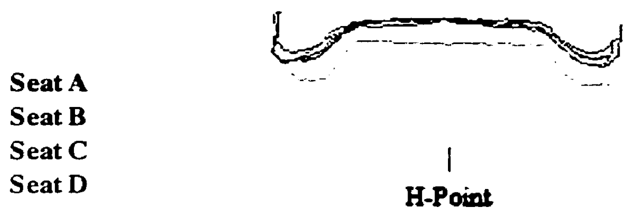


Figure 53: Seatback Section +200 mm from H-Point

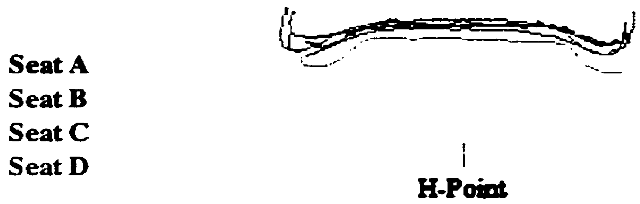


Figure 54: Seatback Section +250 mm from H-Point

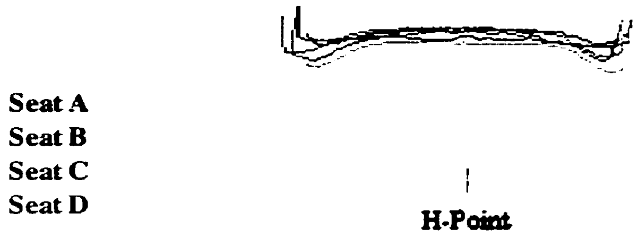


Figure 55: Seatback Section +300 mm from H-Point

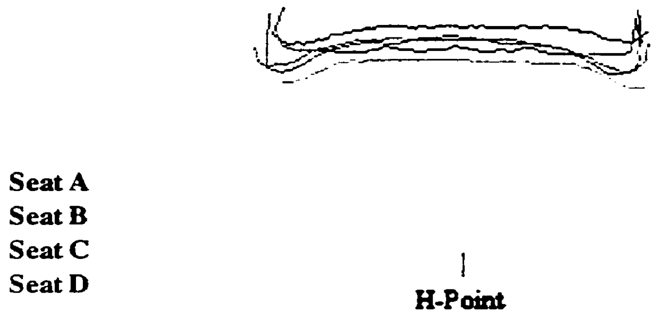


Figure 56: Seatback Section +350 mm from H-Point

The scan data were then dimensioned using the operational definitions presented in Chapter 3. The results are included in Table 45.

Table 45: Cushion and Seatback Dimensions obtained from Scan Data

Dimension	Section	Seat A	Seat B	Seat C	Seat D	Seat E	Mean	STD	Min	Max
Cushion										
Cushion Width (mm)										
	H-Point	428	484	481	445	414	450	31	414	484
	+50 mm	474	504	492	467	449	477	21	449	504
	+100 mm	457	516	519	503	492	497	25	457	519
	+150 mm	457	522	534	525	495	507	31	457	534
	+200 mm	510	551	537	523	492	523	23	492	551
	+250 mm	495	516	525	526	491	511	17	491	526
	+300 mm	425	510	503	512	444	479	41	425	512
Cushion Insert Width (mm)										
	H-Point	291	314	290	272	321	298	20	272	321
	+50 mm	291	325	286	280	330	302	23	280	330
	+100 mm	295	342	278	288	332	307	28	278	342
	+150 mm	305	354	289	296	341	317	29	289	354
	+200 mm	328	361	262	304	355	322	41	262	361
	+250 mm	354	370	238	311	358	326	54	238	370
	+300 mm	372	378	218	320	377	333	69	218	378
Cushion Bolster Height (mm)										
	H-Point	23	43	46	33	23	34	11	23	46
	+50 mm	40	51	53	40	33	43	8	33	53
	+100 mm	49	57	68	48	40	52	11	40	68
	+150 mm	49	52	69	52	39	52	11	39	69
	+200 mm	52	46	58	44	33	47	9	33	58
	+250 mm	33	29	43	33	21	32	8	21	43
	+300 mm	0	12	25	22	6	13	11	0	25
Cushion Length (mm)		351	341	362	352	357	353	8	341	362
Cushion Angle (°)		18	19	11	9	10	13	5	9	19
Seatback										
Seatback Width (mm)										
	H-Point	465	498	501	512	454	486	25	454	512
	+50 mm	488	522	525	512	445	498	33	445	525
	+100 mm	463	523	527	514	465	498	32	463	527
	+150 mm	486	517	536	512	478	506	24	478	536
	+200 mm	462	517	522	515	477	499	27	462	522
	+250 mm	460	512	527	517	475	498	29	460	527
	+300 mm	451	508	514	507	462	488	30	451	514
	+350 mm	464	502	488	485	451	478	20	451	502
	+400 mm	373	492	459	467	443	447	45	373	492
Seatback Insert Width (mm)										
	H-Point	289	310	370	288	272	306	38	272	370
	+50 mm	283	311	364	298	263	304	38	263	364
	+100 mm	285	313	346	332	271	309	31	271	346
	+150 mm	287	314	323	300	274	300	20	274	323
	+200 mm	294	319	306	288	283	298	15	283	319
	+250 mm	329	325	275	278	289	299	26	275	329
	+300 mm	451	329	219	251	307	311	89	219	451
	+350 mm	464	334	194	259	314	313	100	194	464
	+400 mm	373	339	183	233	317	289	79	183	373
Seatback Wing Height (mm)										
	H-Point	59	41	55	18	31	41	17	18	59
	+50 mm	65	58	69	37	52	56	13	37	69
	+100 mm	74	74	79	42	62	66	15	42	79
	+150 mm	84	71	89	55	73	74	13	55	89
	+200 mm	69	65	86	57	72	70	11	57	86
	+250 mm	41	57	67	58	60	57	10	41	67
	+300 mm	26	45	32	57	54	43	14	26	57
	+350 mm	24	37	15	48	37	32	13	15	48
	+400 mm	13	27	2	45	26	23	16	2	45
Seatback Height (mm)		539	559	554	576	569	559	14	539	576
H-Point to Apex of Lumbar (x) (mm)		157	175	167	166	181	169	9	157	181
H-Point to Apex of Lumbar (z) (mm)		89	124	116	143	143	123	22	89	143

The assumption is that the data in Table 45 impact seat interface pressure, which, based on the previously discussed results, is related to subjective perceptions of comfort. If the assumption holds, it should be possible to derive an optimal seat geometry and contour. Design teams, armed with recommended ranges for all the parameters listed in Table 45, would be more likely to produce comfortable seats. Since this research demonstrated that Seat C was the most comfortable, it would be inappropriate to develop seat geometry and contour guidelines without using Seat C as the starting point. Specifically, the upper and lower limits of the recommended ranges were set by taking Seat C's geometry and contour data and then adding/subtracting half of the sample standard deviation. The remainder of this chapter presents seat design guidelines and discusses how they are related to preexisting, although limited, anthropometric data.

4.5.1 Cushion Design Guidelines

Based on anthropometric data compiled by the Anthropology Research Project (1989), a cushion width of 432 mm (measured through H-Point) should be adequate for a single position. By adding allowances for clothing and freedom of movement, the recommended range is 465 - 495 mm. From this it is possible to define a cushion insert width (through H-Point) of 280 - 300 mm. This requirement primarily constrains the position of the cushion bolsters and frame components within 140 - 150 mm of the seat centerline. In considering lateral clearance, if the cushion bolsters are stiffer than the insert area because of interference from the frame components, a hammocking effect (which results in excessive lateral pressure) will constrict the occupant's buttocks, causing the seat to feel too narrow even if the dimensional specifications are met. A cushion bolster height that is greater than 40 - 50 mm (through H-Point) would have a similar effect. Note that Seat C (Figure 43 - 48) is relatively flat in the insert area. Therefore, the previously described hammocking effect is not an issue.

Up until approximately 200 mm forward of H-Point, the cushion should continue to get progressively wider. At this section the cushion should be 525 - 545 mm wide. In fact, the section 250 mm forward of H-

Point is still wider than the section through H-Point (515 - 535 mm to 465 - 495 mm), although not as wide as the section 200 mm forward of H-Point. The increased width allows the legs to splay. Leg splay is used by the occupant to optimize the cushion pressure distribution profile. To allow for leg splay the combination of insert width and bolster height should not be overly restrictive. This can be accomplished by progressively increasing the bolster height from 40 - 50 mm (through H-Point) to 65 - 75 mm (150 mm forward of H-Point) and then progressively decreasing the bolster height to 40 - 50 mm (250 mm forward of H-Point). Designers should also ensure that the transition between the insert and the bolsters is smooth (consider Seat C in Figure 43 - 48).

The trim construction of the cushion, in terms of design sew locations, defines, to a large extent, the appearance of the seat. Recall, from the previous analysis, that comfort and appearance are related. In the compact car segment, it appears as though occupants prefer the trim design illustrated in Figure 57 (top view of sitting surface).

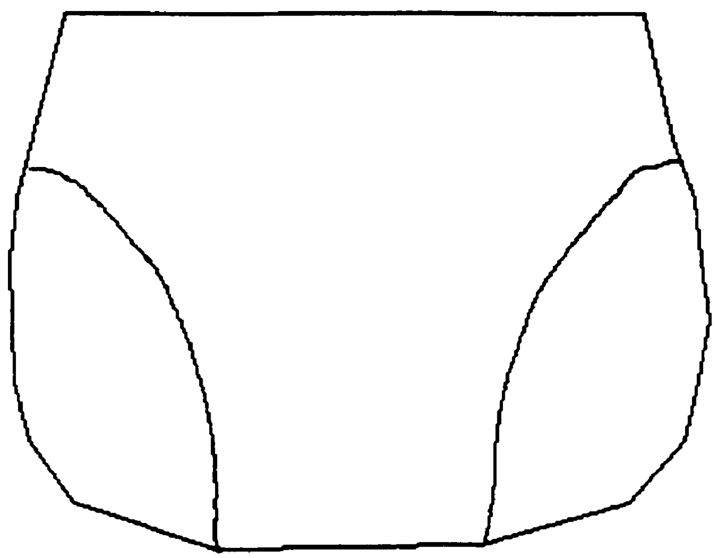


Figure 57: Recommended Cushion Trim Construction. Trim construction deals with seat style and, therefore, ratings of aesthetic quality.

The cushion length guideline, based on this research, is 355 - 365 mm. In order to compare this guideline to those cited in the literature review, it is necessary to determine the horizontal distance from H-Point to the contact point on the seatback. Schneider et al. (1985) found that this distance is approximately 135 mm. Therefore, adding 135 mm produces a guideline equal to 490 - 500 mm. This is greater than Keegan's recommendation of 432 mm but within the range outlined by Grandjean (1980) (i.e., 440 - 550 mm). Since 490 - 500 mm is greater than the 5th percentile female buttock-to-popliteal length of 440 mm, this analysis suggests that cushion length, as a seat design factor, has not been optimized for small occupants (even with Seat C). An adjustable length cushion could be used to provide more thigh support for larger people, but only a small range of adjustability is needed. The 95th percentile male buttock-to-popliteal length is 546 mm (Anthropology Research Project, 1989). A cushion length increase of 46 - 56 mm (from 490 - 500 mm) should, therefore, be considered the maximum necessary.

For occupants with long legs, the cushion may feel too short if the cushion angle relative to the horizontal is too small. Under these circumstances, only the buttocks of long-legged occupants come in contact with the seat. The recommended cushion angle is 9 - 13°. In this context, an adjustable cushion angle may be more appropriate than an adjustable cushion length.

4.5.2 Seatback Design Guidelines

The recommended seatback width and seatback insert width through H-Point is 490 - 510 mm and 350 - 390 mm, respectively. The total seatback width at the section 300 mm from H-Point is slightly wider at 500 - 530 mm. The insert width through this same section is 175 - 265 mm. The insert area as a whole gets progressively narrower from H-Point to the upper seatback. Note that the seatback width guidelines presented in this paragraph are slightly greater than those outlined in the literature review.

The sensation of lateral support can be created by providing 45 - 65 mm of seatback wing height through H-Point. The wing height should increase up until 150 mm from H-Point. To avoid lateral restrictions in the upper back region, the wings should become progressively less pronounced from 150 mm above H-Point to 350 mm above H-Point. In fact, at 350 mm from H-Point the recommended seatback wing height is only 10 - 20 mm. Once again, note that the wing height recommended in this paragraph is greater than wing height outlined in the literature review. The greater wing height should be offset by the greater seatback width recommended in the preceding paragraph.

The trim construction in the insert area of the seatback, just as the insert area of the cushion, defines the appearance of the seat. In the compact car segment, it appears as though occupants prefer the trim design illustrated in Figure 58 (view of sitting surface).

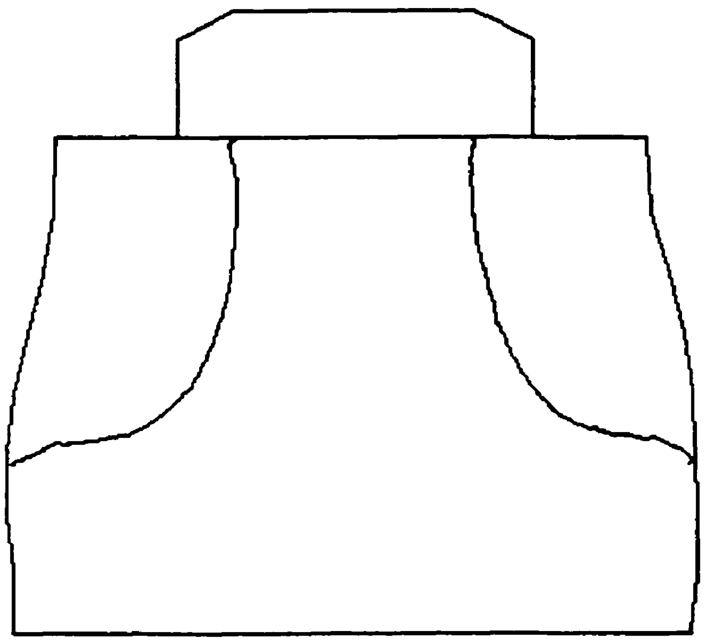


Figure 58: Recommended Seatback Trim Construction. Trim construction deals with seat style and, therefore, ratings of aesthetic quality.

The seatback height should extend 550 - 560 mm from the biteline. This is compatible with the constraints imposed by FMVSS 202 (U.S. Office of Federal Register).

In line with the recommendation presented by Reed et al. (1994), the apex of the lumbar contour should be located 105 - 125 mm above H-Point. In terms of prominence, the apex should protrude 160 - 170 mm. It should be noted that a four-way adjustable lumbar would, probably, enhance comfort.

As part of this discussion, it is important to realize that vehicles differ in character, ride, and handling. Therefore, all vehicle seats should not be alike. Seat designs must be matched to the vehicles in which they are to be used. Sport cars, for example, do not generally use plush, soft seats, nor do luxury cars generally use firm, highly contoured seats. Combinations of certain portions of these characteristics can be selectively mixed to produce seats for specialty vehicles. The aforementioned guidelines, therefore, only apply to seats from the compact car segment. In terms of classification, the studied seats were of medium firmness and contouring.

4.5.3 Summary of Seat Contour and Geometry Design Guidelines

Table 46 summarizes the seat comfort design guidelines derived from this research. Within the limits of the guidelines, it is possible to design an automobile seat with drastic changes in shape. As an example, a cushion insert that measures 300 mm (through H-Point) to 275 mm (+50 mm from H-Point) to 290 mm (+100 mm from H-Point) to 275 mm (+150 mm from H-Point) to 280 mm (+200 mm from H-Point) to 215 mm (+250 mm from H-Point), even though it satisfies the guidelines, should be avoided. This is definitely atypical and the inconsistencies would probably receive negative comfort ratings from compact car consumers. Common sense should be employed when interpreting the guidelines.

Table 46: Seat Contour and Geometry Design Guidelines

Dimension	Section	Guidelines
Cushion		
Cushion Width (mm)		
	H-Point	465 - 495
	+50 mm	480 - 500
	+100 mm	510 - 530
	+150 mm	520- 550
	+200 mm	525 - 545
	+250 mm	515 - 535
Cushion Insert Width (mm)		
	H-Point	280 - 300
	+50 mm	275 - 295
	+100 mm	260 - 290
	+150 mm	275 - 305
	+200 mm	240 - 280
	+250 mm	215 - 265
Cushion Bolster Height (mm)		
	H-Point	40 - 50
	+50 mm	50 - 60
	+100 mm	65 - 75
	+150 mm	65 - 75
	+200 mm	55 - 65
	+250 mm	40 - 50
Cushion Length (mm)		355 - 365
Cushion Angle (°)		9 - 13
Seatback		
Seatback Width (mm)		
	H-Point	490 - 510
	+50 mm	510 - 540
	+100 mm	510 - 540
	+150 mm	525 - 535
	+200 mm	505 - 535
	+250 mm	510 - 540
	+300 mm	500 - 530
	+350 mm	480 - 500
Seatback Insert Width (mm)		
	H-Point	350 - 390
	+50 mm	345 - 385
	+100 mm	330 - 360
	+150 mm	315 - 335
	+200 mm	295 - 315
	+250 mm	260 - 290
	+300 mm	175 - 265
	+350 mm	145 - 245
Seatback Wing Height (mm)		
	H-Point	45 - 65
	+50 mm	65 - 75
	+100 mm	70 - 90
	+150 mm	80 - 100
	+200 mm	80 - 90
	+250 mm	60 - 70
	+300 mm	25 - 35
	+350 mm	10 - 20
Seatback Height (mm)		550 - 560
H-Point to Apex of Lumbar (x) (mm)		160 - 170
H-Point to Apex of Lumbar (z) (mm)		105 - 125

5. CONCLUSION

Technology has changed automobiles over the years. As a result, consumer expectations, in terms of automobile performance, have risen. Factors like comfort and safety are important attributes that a consumer demands in an automobile. The seat has a huge role to play in fulfilling customer expectations. With this said, the seat comfort design process needs to change in order to (a) meet customer expectations and (b) reduce development time and ultimately cost.

Tools like seat interface pressure have been available to the automotive seating industry for some time. The technology is, unfortunately, useless without an understanding of how the output relates to subjective perceptions of comfort. One of the problems with past seat comfort quantification efforts is that there was no good way to translate perceptions of comfort into something tangible. While the surveys used and the studies performed by seat system design teams offered credible evaluations in terms of face validity, the comparisons were poor in terms of experimental rigor. Consequently, the results were questionable on the grounds of methodological weaknesses. This dissertation addresses these concerns and puts forward a standard benchmark against which all present and future automobile seat comfort surveys may be evaluated. In this way, comfort development, not to mention prediction capability, should no longer be hindered by the lack of an acceptable subjective instrument.

This was accomplished by, first, demonstrating that the nonparametric approach to survey data analysis (recommended by some purists), which is a departure from the industry wide norm, is unnecessary. A parametric analysis was, therefore, warranted. This was an important result because skeptics of the value of seat comfort development and even those who think that comfort quantification is a worthwhile pursuit will be "turned off" by the suggestion that non-familiar statistics should be applied. The contention that parametric statistics can be used for ordinal type data has never before been shown in the context of automobile seat comfort.

Having established this, it was possible to use a parametric approach to develop a survey with an acceptable level of test-retest reliability, internal consistency, criterion-related validity, and construct validity. A survey cannot and should not be used to evaluate seats unless it is subjected to the type of scrutiny used in this manuscript. The survey was designed with special emphasis on the wording of the survey items, the type and number of rating scale categories, the verbal tags associated with the categories, and the interest and motivation of the respondent (as a function of survey length).

A case study using five seats, each evaluated by 12 subjects, was then used to present the manner in which meaning can justifiably be attached to the survey. The outlined process is expected to greatly improve seat design efforts. As an interesting aside, when the data analysis approach was used to rank the five seats, the results were exactly the same as those found in J.D. Power & Associates' annual seat quality report. In some respects, this fact, in and of itself, validates the survey.

In terms of future work, it is recommended that the same process be followed to develop a survey to assess the dynamic properties of the seat (i.e., ride quality). The fact that the survey was developed using seats evaluated under showroom conditions must be considered a limitation. For example, insufficient lumbar support (Item A in Table 13) in a showroom setting may not be perceived as insufficient lumbar support in long-term driving conditions. It is important to realize that the meaning of the verbal tags might vary considerably as a function of context.

Seat comfort could not be legitimately predicted if the measurement methods produced vastly different outputs under consistent test conditions. With this fact as the impetus, pressure measures were shown to be repeatable in a test-retest scenario. This may seem like a trivial result but it has never before been demonstrated in the context of automobile seating using human subjects. The calibration procedure and the environmental controls (temperature and humidity) also rule out the effects of drift, temperature sensitivity, and sensor durability. Together these findings lend credibility to the method used to quantify automobile seat comfort.

Due to a lack of emphasis on the educational side of automobile seat usage, seat features designed to enhance comfort are not having as great an impact as design teams intended. Published literature dealing with the effects of driver selected seat position was found to be lacking. This gap in knowledge was addressed by (1) developing and validating a model to predict driver selected track position as a function of demographic and anthropometric characteristics and (2) providing commentary, based on ergonomic principles, on how to adjust the seat for maximum comfort and safety. If this information can somehow be communicated to the consumer (perhaps through the owner's manual), then achieving a comfortable position would become more likely.

Driver selected seat position should, in the future, be studied using seats from higher-end vehicle segments. This is advisable because higher-end seats, typically, have more features. The studied vehicle segment (i.e., compact car) could not be used to address the fact that most high-end seat tracks are, for example, angled several degrees to the horizontal so that moving the seat forward also raises the seat. This is appropriate since occupants with shorter legs usually also have shorter torsos, and the added height helps to achieve an acceptable eye position. Cushion angle adjustment, which was, once again, not a feature any of the studied seats possessed, is also useful in conjunction with the recommended angled track. To comfortably reach the pedals, smaller drivers may find it preferable to flatten out the seat as it is raised, while long-legged drivers, in order to preserve reach to the steering wheel, might increase the cushion angle to allow a more reclined seatback angle. Seat system design teams would like to know how much cushion angle adjustment is necessary to (1) accommodate the preferences of occupants of different sizes (engineering perspective) and (2) optimize circulation to the underside of the thighs (physiology perspective). Using the approach documented in this dissertation, recommended starting positions could be provided for all types of seat adjustments.

From a broader perspective, the overall comfort index defined in this manuscript was used as the dependent variable in the development of a prediction model. The input variables in the model included (1) seat interface pressure measurements, (2) subject anthropometry and demographics, and (3) perceptions of seat appearance. In this way, the link between objective measures and subjective perceptions was established and validated. Using this model, human criteria for seat interface pressure parameters were established. While this is a valuable contribution, especially in the context of product validation testing, seat system design teams need to understand how to impact the objective measures related to comfort prior to building a prototype. To this end, seat geometry and contour design guidelines were derived. The model, together with the design guidelines, is expected to make comfortable seat design the norm rather than the exception. This is more than can be said about the current process.

Anthropometric data were considered when developing the design guidelines. The quality of anthropometric data must be considered a limitation. More specifically, the anthropometric values cited in this dissertation were obtained from a survey of American military personnel conducted by the Anthropology Research Project (1989). While this survey has a large number of anthropometric measures available, the data are limited by the fact that the military sample has a narrower age range and probably includes subjects who are more physically fit, on average, than the general North American driving population. Unfortunately, at present this is the most comprehensive anthropometric database available. CAESAR is expected to address this limitation. CAESAR is an abbreviation for Civilian American and European Surface Anthropometry Resource. This is a cooperative research program that contains partners from the ground vehicle, aerospace, and apparel industries. The project's objective is to capture representative body sizes of the current American and European populations. Once available, the automotive seating can use the CAESAR data to (1) select truly representative subject samples for research studies and (2) better optimize seat geometry and contour.

To reiterate, the seats studied were all from the compact car segment. Therefore, the prediction models presented as part of this dissertation can only confidently be applied to the studied segment. The belief is that seats from different vehicle segments (e.g. sporty, luxury car, van, etc.) have different characteristics and, therefore, comfort properties. This belief needs to be substantiated with data. For this reason, it makes sense, as part of future research, to study seats from different vehicle segments to determine if there are segment specific differences. If differences are found, then seat suppliers would be wise to create a few segment specific models per year. Once all the segment specific models are created, the original segments need to be re-visited and the models need to be updated to reflect the fact that perceptions of comfort will, inevitably, change with time. If there are no segment specific differences, it is still important to monitor the single model to ensure that it performs well when applied to new programs. From a research perspective, the effort will, however, be less involved (i.e., fewer seats will be required). Either way, the recommendation is for the automotive seating industry to use the approach outlined in this dissertation to continuously improve the prediction models.

Without considering the growth of the international automotive market, efforts to quantify comfort must be considered incomplete. For this reason, seats from other parts of the world need to be investigated using subjects from the intended markets. The assumption is that perceptions of comfort are unique to different parts of the world. For example, Western Europeans, as compared to North Americans, are, generally, thought to prefer firmer seats. Data are required to support or refute these types of claims.

To enable optimized, automatic adjustment of an automobile seat it may be possible to combine the comfort position findings with the seat interface pressure findings. More specifically, seat position can, quite feasibly, be determined from occupant anthropometry by means of pressure sensors built into the foam of the seat. The pressure values can then be analyzed and compared to postures and the level of comfort associated with them. At this point, seat position can be instantaneously adjusted based on a single reading of the pressure sensors (i.e., default settings) or customized to occupant preferences (i.e., memorized personal options). Another interesting possibility is continuous, intelligent adjustment. This can only be accomplished by taking advantage of the force movie capability of the seat interface pressure technology. In other words, seat interface pressure needs to be considered over time. If successfully implemented in the realm of automobile seating, these concepts can be extended to apply to other types of seating (airplane seating being the most notable).

This manuscript has alluded to the fact that, in addition to comfort, the health and safety of the occupant are affected by seat design. Here this point will be elaborated on in the context of recommendations for future research. Many researchers have linked lower back pain to long periods of driving (Kelsey et al., 1987; Heliovaara, 1987). Previously Troup (1978) identified postural stress, vibration, muscular effort, and impact and shock as the cause of lower back pain in drivers. Postural stress is exposure to long-term sitting in the same position. Vibration is transmitted from the automobile through the seat. Muscular effort contributes to occupant fatigue. Impact and shock are road hazards. In these factors exposure is the critical parameter. The automobile seat's role in limiting exposure to these factors should be investigated with special emphasis on low back pain.

From a safety perspective, the seat is structurally an integral part of the occupant restraint system. The shoulder and lap belts have been attached to inertial reels that permit occupants to change their position. The evaluation of automobile seat comfort needs to consider the restraint system. For example, the belt, crossing an occupant's body, follows a minimum path principle (Searle, 1974). Attachment locations and the shape of the seated occupant's body control belt path. Some occupants find the path across their neck and shoulders (States et al., 1987) or over their pelvis (Sato, 1987) uncomfortable. A review of accident data shows that some occupants do not wear seat and shoulder belts or wear them improperly. Thus, the effects of restraint parameters on seat comfort should be evaluated.

In this study, the center of force was studied in relation to the load. Recall that the load at the center of force for the cushion and seatback were considered input variables for the overall comfort index prediction model. The location of the center of force may, however, be an important parameter in the development of occupant detection systems for safe airbag deployment. Injuries or, in some cases, deaths, have made safe airbag deployment for smaller passengers (particularly children) a big issue. The automotive seating industry has reacted by attempting to create smart seats (i.e., seats that know when to deploy). It can be speculated that the location of the center of force will, probably, be different for adults, children, and other objects. It may, consequently, be possible to design a seat with sensors that can detect differences in center of force location. The end product would be a safer seat because the airbag would not deploy when occupied by children or other objects (eg. briefcase, grocery bags, golf bag, etc.).

This research was, obviously, geared toward applications at the complete seat level (i.e., Tier 1 supplier level). At the component level (i.e., Tier 2 supplier level) it may be useful to predict comfort in specific regions. As an example, suppliers of lumbar mechanism may adopt a similar but more focused approach to predict subjective perceptions of lumbar comfort. A preliminary idea involves assessing seat interface pressure characteristics in the lumbar region by dividing the pressure sensitive mats into an area corresponding to the lumbar region. An immediately apparent shortcoming is the fact that the pressure sensitive mats need to be arbitrarily divided into regions by the researcher. In this way, subjectivity is being introduced into the process. Comfort assessment must become more scientific if it is to be embraced by seat system design teams.

In addition to geometry and contour, design recommendations are required for foam firmness. Just like geometry and contour, firmness will, probably impact seat interface pressure (particularly peak pressure and total force). Altering the foam formulation can vary firmness. Design recommendations will, therefore, need to be reduced to a chemistry level.

Emerging technologies such as neural networks have many potential industrial applications in diagnostics, modeling, and control. With this said, it should be possible to train a neural network to learn the relationships between design features, human attributes, and comfort measures. Based on this work, a two-tiered neural network linking seat geometry and contour (i.e., design parameters) to seat interface pressure (an intermediate dependent variable) to the overall comfort index may be appropriate. In this way, the design is related to the measurable, which is related to the perception of comfort.

Seat C was the most comfortable compact car seat in this study. This seat was not designed using the human criteria and design guidelines presented as part of this research. There are, therefore, seat system design teams that have successfully developed comfortable automobile seats. These teams should be surveyed to extract their experiences and knowledge. The findings could be used to validate the formalized design guidelines.

All research requires assumptions. This section will conclude in a list of assumptions that should (a) set the theoretical framework for the present investigation and (b) allow the interested reader to derive other ideas for future research.

- Automobile seat comfort affects purchasing decisions (i.e., seat comfort is a product differentiator).
- Seat system design teams strive toward minimizing discomfort or maximizing the level of positive comfort.
- Current design and development practices, which are inefficient and outdated, have a low success rate in terms of producing comfortable automobile seats.
- Consumers evaluate automobile seat comfort subjectively.
- Seat system design teams need objective, measurable laboratory standards that can be linked to subjective perceptions of comfort. In this way, seat designs can be evaluated and distinguished.
- Quantification methods are meaningless without an understanding of what occupants perceive as comfortable. The best way to obtain this understanding is through the administration of a reliable and valid survey.
- Seat system design teams need reliable and valid survey data in order to develop prediction models and design guidelines. Present day prediction capability has been hindered by the lack of an acceptable subjective instrument.
- The automobile seat comfort development process could be improved if more attention was paid to the quantitative aspects of survey design and analysis.
- The role of survey data is not expected to diminish with time. As perceptions of comfort evolve (a seat design that is comfortable today may not necessarily be comfortable tomorrow) and new measuring techniques are developed, survey data will be required to update prediction models and design guidelines.

- The vehicle interior is a workstation – the driver's seat is one constituent element.
- Driver-selected seat position (i.e. posture) is a compromise between what is good and what is practical.
- Seat comfort cannot be quantified without first defining a space in which a postural compromise is possible.
- Individual preferences in adjustment need to be understood and accommodated.
- Advances in seat adjustability, in terms of many and varied features, are overwhelming and intimidating consumers.
- Consumers would be more satisfied with their automobile seats if they were provided with more direction on how to take advantage of the features, in terms of seat adjustment, designed to enhance comfort.
- A scientific method will elevate seat interface pressure into a standard objective measure of seat comfort.
- Seats from the same vehicle segment have comparable H-Point to Heel Point relationships (i.e. vehicle packages).
- Subjects are consistent in their selection of seat position.
- Subjects cannot recall their survey responses after a period of five months.
- Driver preferred seatback angle is dependent on vision requirements and steering wheel location.
- Driver preferred track position is dependent on seat height, cushion angle, and pedal location.
- Once fatigue has set in, seat adjustment will not alleviate discomfort.
- Seat design characteristics related to contour and geometry affect seat interface pressure measures.
- Consumers have segment specific seat comfort criteria (e.g. compact cars vs. luxury cars vs. sporty cars). Segment specific contour and geometry guidelines and prediction models are necessary to satisfy different comfort requirements.
- Trim construction affects seat appearance.
- Perceptions of automobile seat comfort are unique to different parts of the world.
- There is an opportunity to optimize automobile seat design based on health considerations (i.e. low back pain).
- Seat interface pressure characteristics (particularly center of force measures) are different for adults, children, and other objects. This has important implications in the design of occupant detection systems for safe airbag deployment based on seat interface pressure technology.

6. APPENDICES

Appendix A: Data used for Survey Development

Test Condition

Seat	Seat #1											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
Appearance Rating	3	4	3	3	2	3	3	2	3	3	2	4
1. Back Tailbum Pressure	1	0	1	0	1	0	0	1	0	0	0	0
2. Location of Lumbar Support	1	-2	0	0	-1	1	1	2	1	0	0	0
3. Amount of Lumbar Support	1	0	0	0	1		1	1	0	0	1	-2
4. Lumbar Comfort	-1	-1	0	0	-1	-1	-1	-1	0	0	-1	-1
5. Amount of Mid-Back Support	-1	0	1	-1	-1	2	0	1	-1	-1	0	0
6. Mid-Back Comfort	-1	0	0	-1	-1	-1	0	-1	-1	0	0	0
7. Amount of Shoulder Support	-1	0	0	0	-2	0	0	0	-2	0	1	0
8. Seat Back Length	0	0	0	0	0	0	0	0	0	0	0	-2
9. Shoulder Comfort	-1	0	0	0	-1	0	0	0	-1	0	-1	-1
10. Amount of Back Lateral Support	-1	0	0	0	0	0	0	-1	0	-1	-1	0
11. Back Lateral Comfort	-1	0	0	0	-1	0	0	-1	0	0	-1	0
12. Seat Back Feel / Firmness	1	0	0	-1	2	0	0	0	0	0	1	0
Seatback Comfort Index	**11**	**3**	**2**	**3**	**12**	**5**	**3**	**9**	**6**	**2**	**7**	**6**
13. Overall Back Comfort	-1	-1	0	0	-1	-1	-1	-1	-1	0	-1	-1
14. Cushion Tailbone Pressure	1	0	0	0	1	1	0	0	1	1	0	0
15. Amount of Ischial / Buttocks Support	1	0	0	-1	-1	-1	0	2	1	-1	0	0
16. Ischial / Buttocks Comfort	-1	0	0	-1	-1	-1	0	-1	-1	-1	0	0
17. Amount of Thigh Support	1	0	2	0	-1	1	-1	0	0	1	2	0
18. Cushion Length	0	0	0	0	0	-1	-1	-1	0	0	-1	0
19. Thigh Comfort	-1	0	-1	0	-1	-1	-1	-1	0	-1	-2	0
20. Amount of Cushion Lateral Support	0	0	-2	0	-1	-2	-1	0	0	-1	1	0
21. Cushion Lateral Comfort	0	0	0	0	-1	-1	-1	0	0	0	-1	0
22. Cushion Feel / Firmness	1	0	0	-1	1	-2	-1	0	-2	-2	1	0
Cushion Comfort Index	**6**	**0**	**5**	**3**	**8**	**11**	**6**	**5**	**5**	**8**	**7**	**0**
23. Overall Cushion Comfort	-1	0	-1	0	-1	-3	-1	-1	-1	-2	-2	0
24. Overall Seat Support	1	0	0	-1		-2	-1	1	-1	-1	1	-1
Overall Comfort Index	**17**	**3**	**7**	**6**	**20**	**16**	**9**	**14**	**11**	**10**	**14**	**6**
25. Overall Seat Comfort	-1	-1	0	0	-1	-2	-1	-1	-1	-1	-2	-1

Seat	Seat #2						
Subject	1	2	3	4	5	6	7
Appearance Rating	4	4	3	4	3	3	4
1. Back Tailbum Pressure	0	0	0	1	0	1	0
2. Location of Lumbar Support	0	1	1	0	-1	-1	1
3. Amount of Lumbar Support	0	-1	1	0	0	0	1
4. Lumbar Comfort	0	-1	-1	-1	0	-1	-1
5. Amount of Mid-Back Support	0	1	0	0	-1	-1	2
6. Mid-Back Comfort	-1	-1	0	0	-1	-2	-1
7. Amount of Shoulder Support	0	0	-2	-3	1	0	0
8. Seat Back Length	0	0	0	-3	0	-1	0
9. Shoulder Comfort	0	0	-1	-3	0	0	-1
10. Amount of Back Lateral Support	0	-2	0	-2	-1	-1	-1
11. Back Lateral Comfort	0	-1	0	-1	-1	-2	0
12. Seat Back Feel / Firmness	0	0	2	0	1	0	2
Seatback Comfort Index	**1**	**8**	**8**	**14**	**7**	**10**	**10**
13. Overall Back Comfort	-1	0		-1	-1	0	-1
14. Cushion Tailbone Pressure	0	0	2	1	0	1	0
15. Amount of Ischial / Buttocks Support	0	0	0	0	0	-1	0
16. Ischial / Buttocks Comfort	0	0	-2	0	0	-1	-1
17. Amount of Thigh Support	0	1	0	0	0	-1	1
18. Cushion Length	1	0	0	-1	-1	0	0
19. Thigh Comfort	0	-1	0	0	-1	-1	-1
20. Amount of Cushion Lateral Support	0	-2	0	-1	0		-1
21. Cushion Lateral Comfort	0	-1	0	-1	0	-2	0
22. Cushion Feel / Firmness	0	0	2	0	1	0	1
Cushion Comfort Index	**1**	**5**	**6**	**4**	**3**	**7**	**5**
23. Overall Cushion Comfort	-1	0	-1	-1	0	-1	-1
24. Overall Seat Support	0	-1		-1	0	-1	1
Overall Comfort Index	**2**	**13**	**14**	**18**	**10**	**17**	**15**
25. Overall Seat Comfort	-1	0	-2	-1	0	-1	-1

Seat	Seat #3												
Subject	1	2	3	4	5	6	7	8	9	10	11	12	13
Appearance Rating	4	4	4		5	2	4	3	4	4		5	4
1. Back Tailbum Pressure	0	0	0	0	0	0	0	0	0	0	0	0	0
2. Location of Lumbar Support	0	0	0	1	0	0	0	0	0	0	0	0	1
3. Amount of Lumbar Support	0	0	0	1	0	0	0	1	0	0	0	0	0
4. Lumbar Comfort	0	0	0	-2	0	0	0	-1	0	0	0	0	0
5. Amount of Mid-Back Support	0	0	0	-1	0	0	0	-1	0	-1	0	0	0
6. Mid-Back Comfort	0	0	0	-1	0	0	0	-1	0	-1	0	0	0
7. Amount of Shoulder Support	0	0	0	-1	0	-1	-1	-1	0	2	0	0	0
8. Seat Back Length	0	0	0	-2	0	0	-2	0	0	0	0	0	-1
9. Shoulder Comfort	0	0	0	0	0	0	-2	-2	0	-1	0	0	-1
10. Amount of Back Lateral Support	0	0	0	0	0	-1	0	2	0	-1	0	0	1
11. Back Lateral Comfort	0	0	0	0	0	0	0	-2	0	0	0	0	-1
12. Seat Back Feel / Firmness	0	0	0	0	0	0	0	0	0		0	0	0
Seatback Comfort Index	**0**	**0**	**0**	**9**	**0**	**2**	**5**	**11**	**0**	**6**	**0**	**0**	**5**
13. Overall Back Comfort	0	0	0	-1	0	0	-2	-1	0	-1	0	0	0
14. Cushion Tailbone Pressure	0	0	1	0	0	0	1	1	0	1	0	1	0
15. Amount of Ischial / Buttocks Support	0	0	1	0	0	0	0	0	-1	-1	0	0	0
16. Ischial / Buttocks Comfort	0	0	-1	0	0	0	0	0	-1	0	0	0	0
17. Amount of Thigh Support	0	0	0	-1	0	1	0	1	0	0	0	-1	-1
18. Cushion Length	-1	-1	0	-1	0	0	-1	0	0	-1	-1	0	-3
19. Thigh Comfort	-1	-1	0	-1	0	-1	0	-1	0	-1	-1	0	-1
20. Amount of Cushion Lateral Support	-1	-1	0	1	0	-2	-1	0	0	-1	0	-1	0
21. Cushion Lateral Comfort	0	0	0	-1	0	0	-1	0	0	0	0	0	0
22. Cushion Feel / Firmness	0	0	1	0	0	0	-1	-1	-1	0	0	1	0
Cushion Comfort Index	**3**	**3**	**4**	**5**	**0**	**4**	**5**	**4**	**3**	**5**	**2**	**4**	**5**
23. Overall Cushion Comfort	0	0	-1	-1	0	0	-1	-1	-1	0	0	0	0
24. Overall Seat Support	0	0	1	-1	0	0	0	1	-1	1	0	0	0
Overall Comfort Index	**3**	**3**	**4**	**14**	**0**	**6**	**10**	**15**	**3**	**11**	**2**	**4**	**10**
25. Overall Seat Comfort	0	0	-1	-1	0	0	0	-1	-1	-1	0	0	0

Retest Condition

Seat #1

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Appearance Rating	3	5	4	3	3	3	3	2	3	3	2	4
1. Back Tailbum Pressure	1	0	0	0	0	0	0	1	0	1	0	0
2. Location of Lumbar Support	1	2	0	0	0	2	0	0	0	0	0	0
3. Amount of Lumbar Support	1	1	0	0	1	2	1	1	0	0	1	-2
4. Lumbar Comfort	-1	-1	0	0	-1	-2	-1	-1	0	0	-1	-1
5. Amount of Mid-Back Support	-1	0	0	0	0	0	0	1	-1	1	0	0
6. Mid-Back Comfort	-1	0	0	0	-1	-2	0	-1	-1	-1	0	0
7. Amount of Shoulder Support	-1	0	0	0	-1	-1	-1	-1	-1	-1	1	0
8. Seat Back Length	0	0	0	0	0	0	-1	0	0	0	0	-2
9. Shoulder Comfort	-1	0	0	0	-1	-2	-1	0	0	0	-1	-1
10. Amount of Back Lateral Support	-1	0	0	-1	0	0	0	0	-1	0	-1	0
11. Back Lateral Comfort	-1	0	0	0	0	0	0	0	-1	0	-1	0
12. Seat Back Feel / Firmness	1	0	1	0	1	0	0	0	0	-1	1	0
Seatback Comfort Index	**11**	**4**	**1**	**1**	**6**	**11**	**5**	**6**	**5**	**5**	**7**	**6**
13. Overall Back Comfort	-1	0	0	0	-1	-2	-1	-1	-1	0	-1	-1
14. Cushion Tailbone Pressure	1	0	1	0	1	0	0	2	0	1	0	0
15. Amount of Ischial / Buttocks Support	1	0	0	-1	1	0	0	1	0	0	0	0
16. Ischial / Buttocks Comfort	-1	0	0	-1	-1	0	0	-1	0	0	0	0
17. Amount of Thigh Support	1	0	1	0	0	1	0	0	0	1	2	0
18. Cushion Length	0	0	0	0	0	-1	-1	0	0	-1	-1	0
19. Thigh Comfort	-1	0	-1	0	-1	-1	-1	0	0	0	-2	0
20. Amount of Cushion Lateral Support	0	0	-1	-1	0	0	-1	0	-1	1	1	0
21. Cushion Lateral Comfort	0	0	0	0	-1	0	-1	0	-1	-1	-1	0
22. Cushion Feel / Firmness	1	0	1	-1	1	0	0	1	0	-1	1	0
Cushion Comfort Index	**6**	**0**	**5**	**4**	**6**	**3**	**4**	**5**	**2**	**6**	**8**	**0**
23. Overall Cushion Comfort	-1	0	0	0	-1	-1	0	-1	-1	-1	-2	0
24. Overall Seat Support	1	0	0	0	-1	2	-1	1	0	-1	1	-1
Overall Comfort Index	**17**	**4**	**6**	**5**	**12**	**14**	**9**	**11**	**7**	**11**	**15**	**6**
25. Overall Seat Comfort	-1	0	0	0	-1	-1	-1	-1	-1	0	-2	-1

Seat #2

Subject	1	2	3	4	5	6	7
Appearance Rating	4	4	3	3	4		4
1. Back Tailbum Pressure	0	0	0	0	1	1	0
2. Location of Lumbar Support	-1	0	0	0	-1	2	0
3. Amount of Lumbar Support	-1	0	1	0	0	-1	0
4. Lumbar Comfort	-1	0	-1	-1	-1	-1	0
5. Amount of Mid-Back Support	0	0	0	0	0	1	1
6. Mid-Back Comfort	0	0	-1	-1	0	-1	-1
7. Amount of Shoulder Support	-1	0	-1	0	-1	1	-1
8. Seat Back Length	0	0	0	0	0	2	0
9. Shoulder Comfort	-1	0	-1	0	-1	-2	-1
10. Amount of Back Lateral Support	0	-1	-1	-1	-1	-2	-2
11. Back Lateral Comfort	-1	0	0	-1	-1	0	-1
12. Seat Back Feel / Firmness	1	1	1	0	0	-1	2
Seatback Comfort Index	**7**	**2**	**7**	**4**	**7**	**15**	**9**
13. Overall Back Comfort	-1	0	-1	-1	-1	0	-1
14. Cushion Tailbone Pressure	0	0	0	1	1	1	2
15. Amount of Ischial / Buttocks Support	0	0	0	-1	0	1	2
16. Ischial / Buttocks Comfort	0	0	-1	-1	0	-1	-2
17. Amount of Thigh Support	0	1	-1	0	0	-1	2
18. Cushion Length	0	-1	-2	-1	0	1	1
19. Thigh Comfort	0	-1	-1	-1	0	0	-1
20. Amount of Cushion Lateral Support	0	-1	0	-1	-1	0	-1
21. Cushion Lateral Comfort	0	0	0	-1	-1	-1	0
22. Cushion Feel / Firmness	0	1	1	0	0	-1	1
Cushion Comfort Index	**0**	**5**	**6**	**7**	**3**	**7**	**12**
23. Overall Cushion Comfort	0	0	-1	-1	0	-1	-1
24. Overall Seat Support	-1	1	-1	-1	0	1	1
Overall Comfort Index	**7**	**7**	**13**	**11**	**10**	**22**	**21**
25. Overall Seat Comfort	-1	0	0	-1	-1	0	-1

Seat #3

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13
Appearance Rating	4	4	4		5	3	4	3	3	4		5	3
1. Back Tailbum Pressure	0	0	0	1	0	0	0	0	0	0	0	1	0
2. Location of Lumbar Support	0	0	0	-1	0	1	0	0	0	1	0	-2	0
3. Amount of Lumbar Support	0	0	0	1	0	0	0	1	0	0	0	0	0
4. Lumbar Comfort	0	0	0	-1	0	-1	0	-1	0	0	0	-1	0
5. Amount of Mid-Back Support	0	0	0	-1	0	1	0	-1	0	-2	0	0	-1
6. Mid-Back Comfort	0	0	0	-1	0	-1	0	-1	0	-1	0	0	-1
7. Amount of Shoulder Support	0	0	0	-1	0	0	0	1	1	0	0	0	1
8. Seat Back Length	0	0	0	-1	0	0	0	0	-1	0	0	0	-1
9. Shoulder Comfort	0	0	0	-1	0	0	0	-2	-1	0	0	0	-1
10. Amount of Back Lateral Support	0	0	0	-1	0	0	0	2	0	0	0	0	0
11. Back Lateral Comfort	0	0	0	-1	0	0	0	-2	0	0	0	0	0
12. Seat Back Feel / Firmness	0	0	0	1	0	1	0	1	0	1	0	0	0
Seatback Comfort Index	**0**	**0**	**0**	**12**	**0**	**5**	**0**	**12**	**3**	**5**	**0**	**4**	**5**
13. Overall Back Comfort	0	0	0	-1	0	-1	0	-1	0	-1	0	0	-1
14. Cushion Tailbone Pressure	0	0	1	0	0	1	1	0	0	1	0	1	0
15. Amount of Ischial / Buttocks Support	0	0	1	0	0	0	0	0	-1	0	0	0	0
16. Ischial / Buttocks Comfort	0	0	-1	-1	0	0	0	0	-1	0	0	0	0
17. Amount of Thigh Support	0	0	0	-1	0	1	0	1	0	1	-1	0	1
18. Cushion Length	-1	-1	0	0	0	0	-1	0	0	-1	-1	0	-2
19. Thigh Comfort	0	0	0	-1	0	-1	0	-1	0	-1	-1	0	-1
20. Amount of Cushion Lateral Support	0	0	0	-1	0	0	-1	0	0	0	0	0	0
21. Cushion Lateral Comfort	0	0	0	0	0	0	-1	0	0	0	-1	0	0
22. Cushion Feel / Firmness	0	0	1	0	0	1	0	0	0	0	-1	0	0
Cushion Comfort Index	**1**	**1**	**4**	**4**	**0**	**4**	**4**	**2**	**2**	**4**	**5**	**1**	**4**
23. Overall Cushion Comfort	0	0	-1	0	0	-1	0	-1	-1	-1	-1	0	-1
24. Overall Seat Support	-1	-1	0	-1	0	1	0	1	-1	1	0	0	0
Overall Comfort Index	**1**	**1**	**4**	**16**	**0**	**9**	**4**	**14**	**5**	**9**	**5**	**5**	**9**
25. Overall Seat Comfort	0	0	-1	-1	0	-1	0	-1	-1	-1	0	0	-1

Seat	Subject	Age (yrs)	Gender	Standing Height (cm)	Body Mass (kg)
1	1	46	0	156	58
1	2	36	1	178	68
1	3	26	0	163	57
1	4	34	1	180	102
1	5	32	1	178	66
1	6	32	0	155	67
1	7	32	1	191	91
1	8	27	0	161	77
1	9	24	1	183	79
1	10	30	1	173	68
1	11	26	1	178	79
1	12	27	1	196	111
2	1	40	0	157	52
2	2	26	0	163	57
2	3	32	1	178	66
2	4	32	1	191	91
2	5	34	1	180	102
2	6	28	1	178	82
2	7	27	0	161	77
3	1	25	1	178	77
3	2	25	1	178	77
3	3	38	0	157	52
3	4	31	1	183	98
3	5	36	1	178	68
3	6	26	0	163	57
3	7	32	1	191	91
3	8	26	1	178	79
3	9	27	1	196	111
3	10	30	1	173	68
3	11	29	1	180	77
3	12	34	0	157	50
3	13	34	1	174	98

Appendix B: Survey Results from Five Seats

	Subj. #1	Subj. #2	Subj. #3	Subj. #4	Subj. #5	Subj. #6	Subj. #7	Subj. #8	Subj. #9	Subj. #10	Subj. #11	Subj. #12
Seat A												
Appearance Rating	4.5	4.5	2.5	4	4	3	4	4.5	4	3	4.5	3
A. Amount of Lumbar Support	-1	-1	-2	0	-1	-1	-1	-1	0	-1	0	-1
B. Lumbar Comfort	-1	-1	-2	0	-1	0	0	-1	0	-1	0	0
C. Amount of Mid-Back Support	-1	0	-1	-1	-1	-1	0	0	-1	0	0	-1
D. Mid-Back Comfort	-1	0	-1	-1	0	0	0	0	-1	0	0	-1
E. Amount of Back Lateral Support	-1	0	-1	-1	0	-1	-1	0	1	-1	0	-1
F. Back Lateral Comfort	-1	0	-1	-1	0	-1	-1	0	-1	-1	0	-1
G. Seat Back Feel / Firmness	0	0	1	0	-1	-1	-1	0	0	-1	-1	-1
Overall Seatback Index	6	2	9	4	4	5	4	2	4	5	1	6
H. Ischial / Buttocks Comfort	0	0	0	0	0	0	0	-1	0	-1	0	0
I. Thigh Comfort	0	-1	-1	-1	-2	-1	-1	0	0	-2	-1	0
J. Cushion Lateral Comfort	0	0	-1	-1	-1	-1	-1	-1	-1	0	-1	0
Overall Cushion Index	0	1	2	2	3	2	2	2	1	3	2	0
Overall Comfort Index	6	3	11	6	7	7	6	4	5	8	3	6
Seat B												
Appearance Rating	4	3.5	2	3	2.5	2.5	2	2.5	3	3	3.5	2.5
A. Amount of Lumbar Support	-2	-2	-2	-1	-1	0	-1	-1	1	-1	-1	-1
B. Lumbar Comfort	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1
C. Amount of Mid-Back Support	-2	-1	-1	-1	0	0	-1	-1	-1	-1	0	0
D. Mid-Back Comfort	-2	-1	-1	-1	0	0	-1	0	-1	-1	0	0
E. Amount of Back Lateral Support	0	0	-1	-1	-1	-2	-1	-1	-1	-1	-1	-2
F. Back Lateral Comfort	0	0	-2	-1	-1	-2	-1	-1	-1	-1	-1	-2
G. Seat Back Feel / Firmness	0	0	-1	-2	-2	-1	-2	-1	-1	-1	-1	-2
Overall Seatback Index	8	6	10	9	6	6	8	6	7	7	5	8
H. Ischial / Buttocks Comfort	0	-1	1	-1	0	-2	-2	0	-1	-1	-1	-1
I. Thigh Comfort	-1	-1	-2	-2	-3	-1	-2	-1	-1	-1	-2	0
J. Cushion Lateral Comfort	0	-1	0	-1	-1	-1	-1	0	-1	-1	-1	-1
Overall Cushion Index	1	3	3	4	4	4	5	1	3	3	4	2
Overall Comfort Index	9	9	13	13	10	10	13	7	10	10	9	10

	Subj. #1	Subj. #2	Subj. #3	Subj. #4	Subj. #5	Subj. #6	Subj. #7	Subj. #8	Subj. #9	Subj. #10	Subj. #11	Subj. #12
Seat C												
Appearance Rating	4.5	4.5	3.5	4.5	4.5	3	5	4.5	5	4.5	5	4.5
A. Amount of Lumbar Support	0	0	0	0	-1	-1	0	0	0	0	0	0
B. Lumbar Comfort	0	0	0	0	-1	-1	0	0	0	0	0	0
C. Amount of Mid-Back Support	0	0	1	1	0	0	0	0	0	0	0	1
D. Mid-Back Comfort	0	0	-1	-1	0	0	0	0	0	0	0	-1
E. Amount of Back Lateral Support	0	0	0	0	0	-1	0	-1	0	-1	0	0
F. Back Lateral Comfort	0	0	0	0	0	-1	0	-1	0	-1	0	0
G. Seat Back Feel / Firmness	1	1	0	0	0	0	0	0	1	0	1	0
Overall Seatback Index	1	1	2	2	2	4	0	2	1	2	1	2
H. Ischial / Buttocks Comfort	0	0	-1	0	0	0	-1	0	0	0	0	0
I. Thigh Comfort	0	-1	0	0	-1	0	0	0	0	0	0	0
J. Cushion Lateral Comfort	-1	0	1	0	0	0	0	0	0	-1	0	0
Overall Cushion Index	1	1	2	0	1	0	1	0	0	1	0	0
Overall Comfort Index	2	2	4	2	3	4	1	2	1	3	1	2
Seat D												
Appearance Rating	5	4.5	3	3.5	5	4	5	3.5	2.5	3	4.5	2.5
A. Amount of Lumbar Support	-1	-1	-1	-1	0	-1	-1	1	1	0	1	0
B. Lumbar Comfort	-1	-1	-1	0	0	-1	-1	-1	-1	0	-1	0
C. Amount of Mid-Back Support	1	-1	0	-1	-1	0	-1	-1	1	-2	0	2
D. Mid-Back Comfort	-1	-1	0	0	-1	0	-1	-1	-1	-2	0	-2
E. Amount of Back Lateral Support	0	-1	-1	-1	-1	-1	0	-2	1	-1	-1	-2
F. Back Lateral Comfort	0	-1	-1	-1	0	-1	0	-2	-1	-1	-1	-1
G. Seat Back Feel / Firmness	-1	-1	-1	-2	0	2	0	0	1	-1	1	1
Overall Seatback Index	5	7	5	6	3	6	4	8	7	7	5	8
H. Ischial / Buttocks Comfort	-1	0	-1	-1	-1	-1	-1	-1	0	-1	0	0
I. Thigh Comfort	-1	-1	-2	-2	-3	-2	-2	-1	0	-1	-1	0
J. Cushion Lateral Comfort	-1	-1	-1	-1	-1	-1	-1	0	0	-1	0	0
Overall Cushion Index	3	2	4	4	5	4	4	2	0	3	1	0
Overall Comfort Index	8	9	9	10	8	10	8	10	7	10	6	8

	Subj. #1	Subj. #2	Subj. #3	Subj. #4	Subj. #5	Subj. #6	Subj. #7	Subj. #8	Subj. #9	Subj. #10	Subj. #11	Subj. #12
Seat E												
Appearance Rating	4.5	4	3.5	3.5	2.5	3	3	2.5	3.5	3	2	3
A. Amount of Lumbar Support	-1	-1	-1	-1	-2	-1	-2	-1	2	-1	-1	-2
B. Lumbar Comfort	-1	-1	-1	-1	-2	-1	-3	-1	-2	-1	-1	-2
C. Amount of Mid-Back Support	-1	0	-1	-1	-1	1	1	1	1	-1	1	1
D. Mid-Back Comfort	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
E. Amount of Back Lateral Support	-2	-2	-2	-1	-1	-1	-1	-2	-1	-2	-1	1
F. Back Lateral Comfort	-2	-2	-2	-1	-1	-1	-1	-2	-1	-2	-1	-1
G. Seat Back Feel / Firmness	-1	-1	1	1	-1	-1	-1	2	1	1	1	1
Overall Seatback Index	10	8	9	7	9	7	10	10	9	9	7	9
H. Ischial / Buttocks Comfort	-1	-1	-1	-2	-2	-2	-1	-1	-1	-1	-1	-1
I. Thigh Comfort	-1	-1	-2	-2	-2	-2	-1	-1	-1	-1	-1	-2
J. Cushion Lateral Comfort	0	-1	-2	-2	-2	-2	-1	-1	-1	-1	-1	-2
Overall Cushion Index	2	3	5	6	6	6	3	3	3	4	3	5
Overall Comfort Index	12	11	14	13	15	13	13	13	12	13	10	14

Appendix C: Driver Selected Seat Position Data

Seat	Subject	Track Position (mm)	Seatback Angle (°)
A	1	895	10
A	2	837	18
A	3	917	15
A	4	885	24
A	5	883	16
A	6	880	14
A	7	726	9
A	8	740	12
A	9	829	16
A	10	882	14
A	11	735	18.5
A	12	716	20
C	1	858	13.5
C	2	848	15
C	3	818	15.5
C	4	898	21.5
C	5	898	17.5
C	6	898	15
C	7	688	13.5
C	8	738	17.5
C	9	828	13.5
C	10	898	14.5
C	11	868	13.5
C	12	798	17
D	1	849	10
D	2	824	14
D	3	859	9
D	4	872	13
D	5	872	13
D	6	872	14
D	7	702	9
D	8	849	11
D	9	799	13
D	10	848	10
D	11	824	11
D	12	702	8

Appendix D: Seat Interface Pressure Data

Seat	Subject	Cushion Contact Area (cm^2)	Cushion Total Force (N)	Cushion Center of Force (g/cm^2)	Cushion Peak Pressure (g/cm^2)	Seatback Contact Area (cm^2)	Seatback Total Force (N)	Seatback Center of Force (g/cm^2)	Seatback Peak Pressure (g/cm^2)
A	1	1634.06	444.5	13	113.0	1105.55	191.6	31	54.6
A	2	1967.48	1010.2	68	145.0	1605.16	305.0	6	83.4
A	3	1811.61	726.4	41	133.0	1652.64	421.6	51	70.6
A	4	1713.55	554.8	9	74.6	1223.22	264.0	19	64.2
A	5	1616.51	592.9	34	160.0	1477.16	360.6	8	135.0
A	6	1657.80	556.9	10	129.0	1302.71	278.7	39	112.0
A	7	1601.03	376.5	23	81.6	1085.93	220.8	36	55.2
A	8	1660.90	558.7	38	122.0	1268.64	223.8	5	47.5
A	9	1794.06	524.8	12	71.1	1328.51	250.3	24	48.8
A	10	1784.77	700.9	0	90.9	1435.87	354.8	37	88.6
A	11	1775.48	568.5	44	107.0	1238.71	211.8	21	46.2
A	12	1584.51	558.6	20	112.0	1091.09	194.7	47	51.3
B	1	1595.87	366.9	17	120.0	989.93	137.4	27	60.7
B	2	1964.38	1065.5	31	135.0	1896.25	362.7	14	73.4
B	3	1716.64	792.7	35	174.0	1682.58	342.9	17	64.4
B	4	1746.58	507.7	27	78.4	1308.90	246.9	40	83.7
B	5	1644.38	646.9	26	247.0	1454.54	322.8	8	103.0
B	6	1683.61	599.5	24	124.0	1166.45	185.6	28	65.7
B	7	1592.77	423.3	0	62.7	1162.32	203.6	30	52.8
B	8	1769.29	584.0	43	142.0	1286.19	193.5	3	43.8
B	9	1686.71	415.8	14	112.0	1356.38	268.5	9	61.8
B	10	1834.32	672.2	17	82.3	1352.26	269.2	19	78.5
B	11	1665.03	457.3	37	90.1	1255.22	170.5	21	43.8
B	12	1493.67	527.7	40	121.0	1143.74	179.1	13	78.5

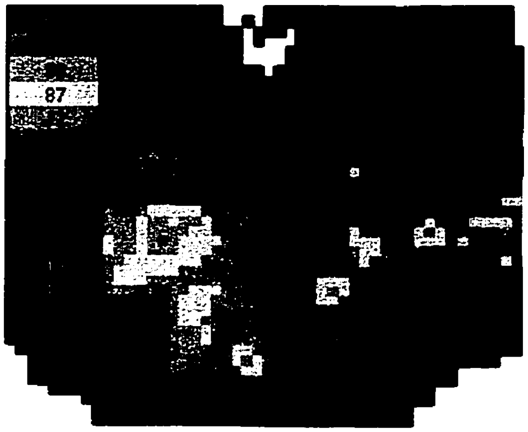
		Cushion				Seatback			
Seat	Subject	Contact Area (cm^2)	Total Force (N)	Center of Force (g/cm^2)	Peak Pressure (g/cm^2)	Contact Area (cm^2)	Total Force (N)	Center of Force (g/cm^2)	Peak Pressure (g/cm^2)
C	1	1628.90	537.2	22	174.0	849.55	140.4	34	214.0
C	2	2001.54	1185.5	44	349.0	1907.61	517.8	8	277.0
C	3	1729.03	784.4	51	139.0	1755.87	416.6	15	70.9
C	4	1810.58	681.3	19	180.0	1281.03	287.4	36	99.3
C	5	1623.74	702.2	21	222.0	1432.77	341.6	15	291.0
C	6	1622.71	668.8	34	173.0	1241.80	241.1	40	62.1
C	7	1710.45	537.9	19	122.0	1206.71	196.7	17	48.3
C	8	1777.54	717.8	40	112.0	1263.48	238.3	17	71.7
C	9	1798.19	577.1	27	82.2	1256.26	213.1	7	59.3
C	10	1735.22	644.0	4	63.2	1493.67	326.9	14	87.2
C	11	1852.90	724.7	3	152.0	1300.64	227.9	12	42.8
C	12	1658.84	600.0	8	123.0	1110.71	177.8	0	60.7
D	1	1493.67	358.9	6	110.0	1005.42	125.6	30	85.6
D	2	1916.90	957.8	56	141.0	1711.48	451.0	41	82.0
D	3	1708.38	718.5	45	112.0	1130.32	278.0	41	85.8
D	4	1583.48	538.5	25	72.8	1209.80	233.6	36	58.4
D	5	1603.09	561.2	39	135.0	1355.35	348.2	22	93.2
D	6	1515.35	545.5	47	105.0	1206.71	256.8	39	106.0
D	7	1681.55	439.3	18	60.5	1181.93	219.1	32	46.0
D	8	1512.26	479.3	41	90.7	1043.61	203.2	34	55.9
D	9	1604.13	496.6	20	173.0	1174.71	181.8	14	100.0
D	10	1722.84	651.3	37	92.9	1223.22	315.1	46	84.5
D	11	1661.93	541.0	37	125.0	1292.38	214.8	20	49.7
D	12	1554.58	485.7	8	96.3	1093.16	172.4	7	49.7

Seat	Subject	Cushion Contact Area (cm^2)	Cushion Total Force (N)	Cushion Center of Force (g/cm^2)	Cushion Peak Pressure (g/cm^2)	Seatback Contact Area (cm^2)	Seatback Total Force (N)	Seatback Center of Force (g/cm^2)	Seatback Peak Pressure (g/cm^2)
E	1	1607.22	424.0	12	86.4	952.77	186.6	50	61.1
E	2	1947.87	970.0	34	159.0	1977.80	557.0	37	83.1
E	3	1748.64	708.0	31	123.0	1530.84	451.8	61	81.8
E	4	1786.84	547.0	36	73.1	1346.06	291.5	48	63.5
E	5	1692.90	541.3	33	86.4	1571.09	453.7	32	117.0
E	6	1703.22	564.1	28	94.0	1275.87	293.2	37	75.7
E	7	1692.90	462.3	4	54.1	1357.42	325.6	40	84.3
E	8	1656.77	519.9	29	95.0	1200.51	277.8	26	59.8
E	9	1708.38	500.9	9	69.3	1336.71	275.0	21	73.3
E	10	1822.96	667.9	16	77.9	1335.74	341.3	60	80.6
E	11	1836.38	593.7	14	71.3	1263.48	153.8	13	47.7
E	12	1493.67	443.7	24	79.8	1150.97	253.0	37	70.8

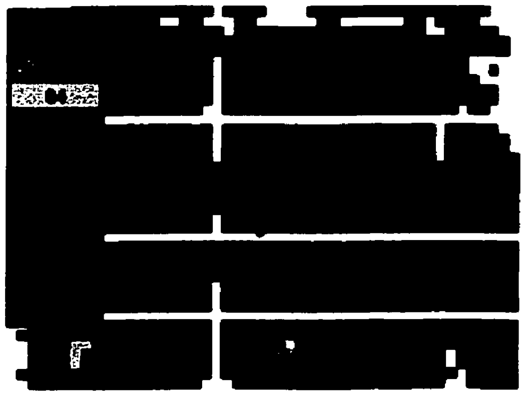
Appendix E: Seat Interface Pressure Distribution Profiles

Subject #1
Cushion
Seat A

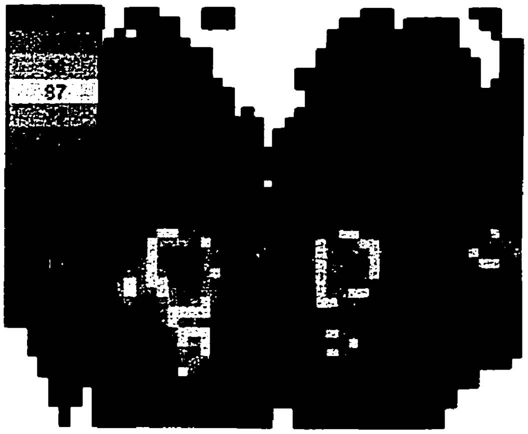
Subject #1
Back
Seat A



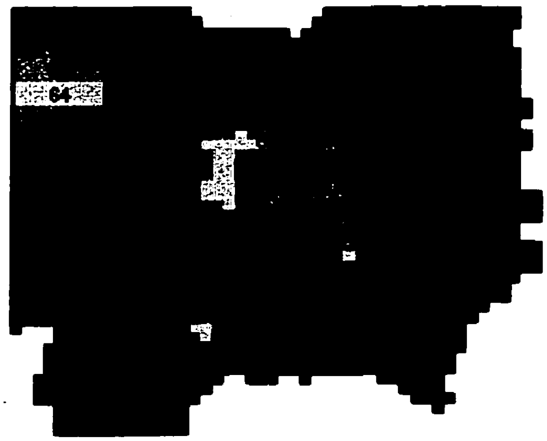
Subject #2
Cushion
Seat A



Subject #2
Back
Seat A



Subject #3
Cushion
Seat A



Subject #3
Back
Seat A

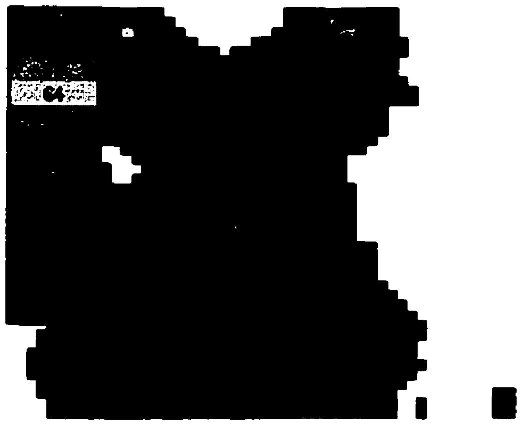
Subject #4
Cushion
Seat A

Subject #4
Back
Seat A

Subject #5
Cushion
Seat A

Subject #5
Back
Seat A

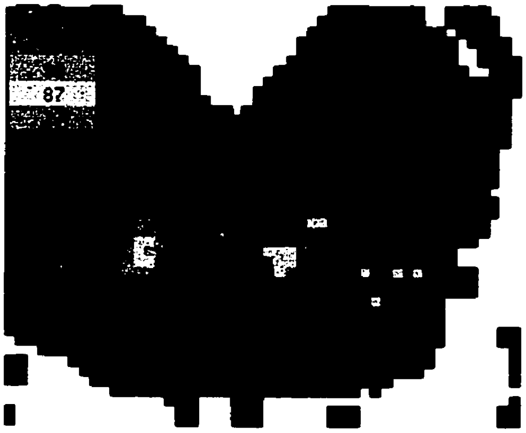
Subject #6
Cushion
Seat A



Subject #6
Back
Seat A

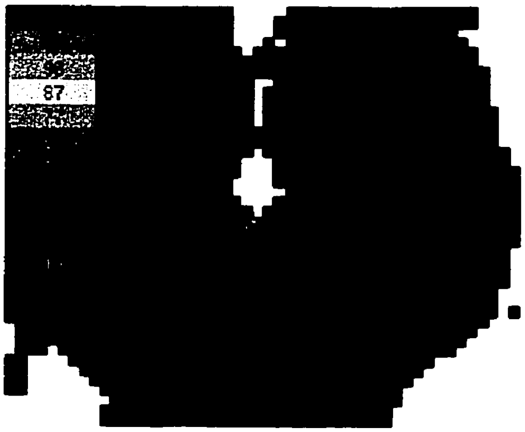
Subject #7
Cushion
Seat A

Subject #7
Back
Seat A

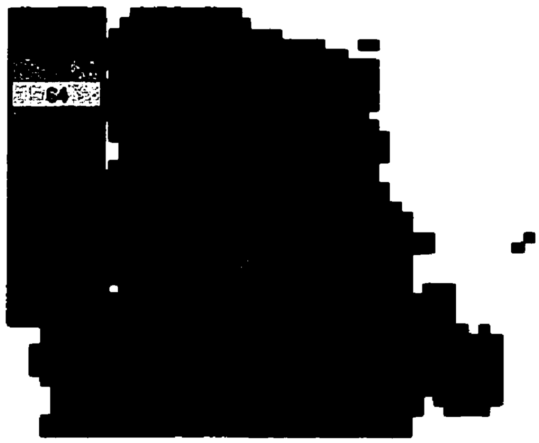


Subject #8
Cushion
Seat A

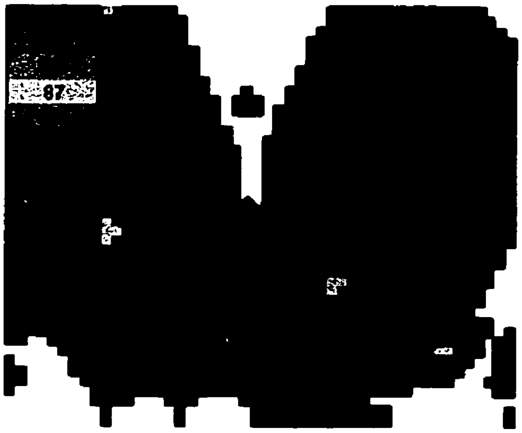
Subject #8
Back
Seat A



Subject #9
Cushion
Seat A

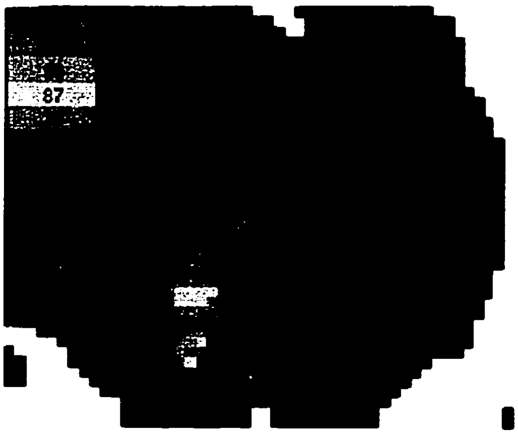


Subject #9
Back
Seat A

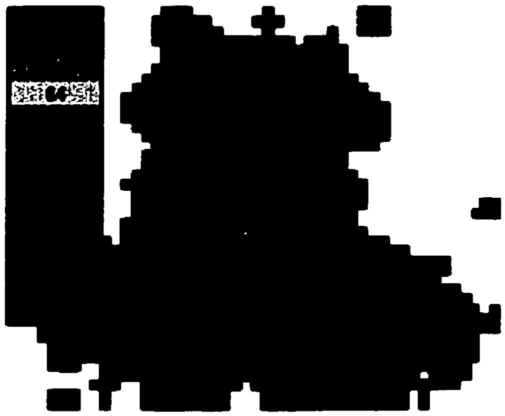


Subject #10
Cushion
Seat A

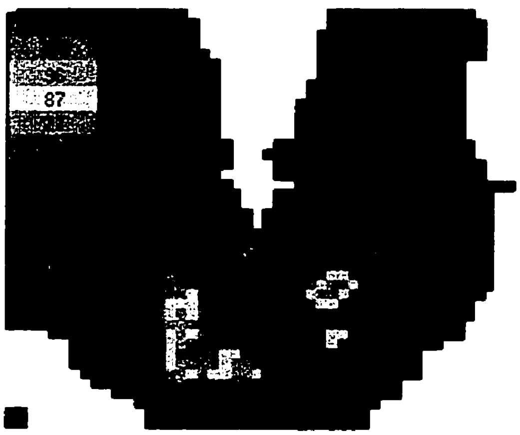
Subject #10
Back
Seat A



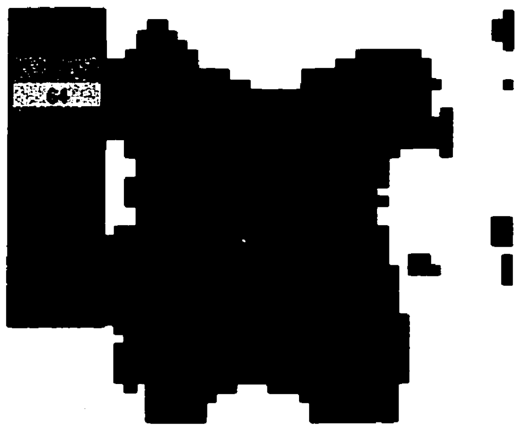
Subject #11
Cushion
Seat A



Subject #11
Back
Seat A

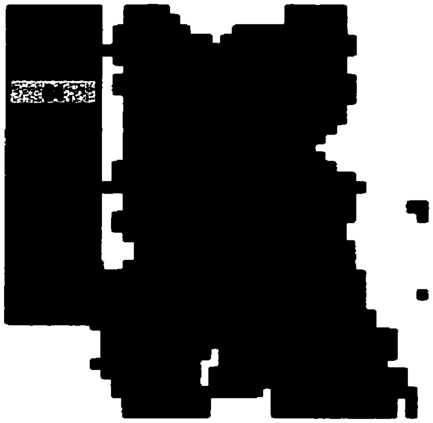


Subject #12
Cushion
Seat A

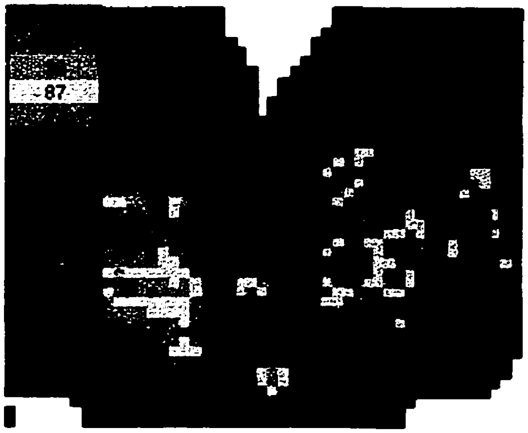


Subject #12
Back
Seat A

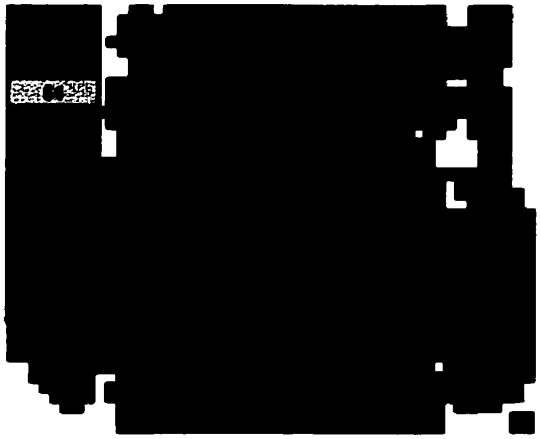
Subject #1
Cushion
Seat B



Subject #1
Back
Seat B

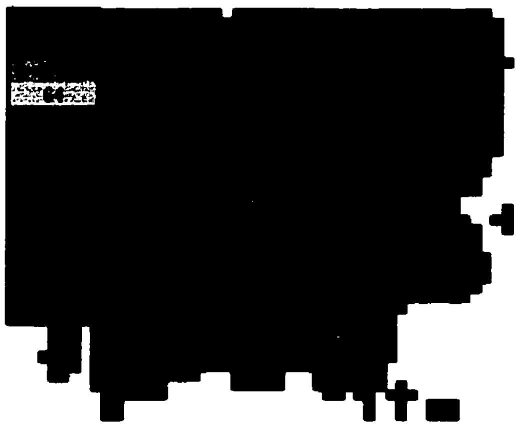


Subject #2
Cushion
Seat B



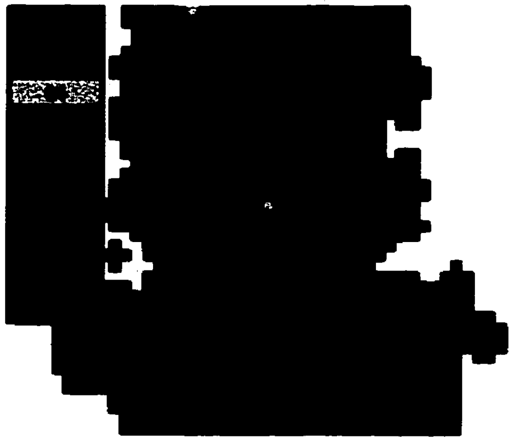
Subject #2
Back
Seat B

Subject #3
Cushion
Seat B

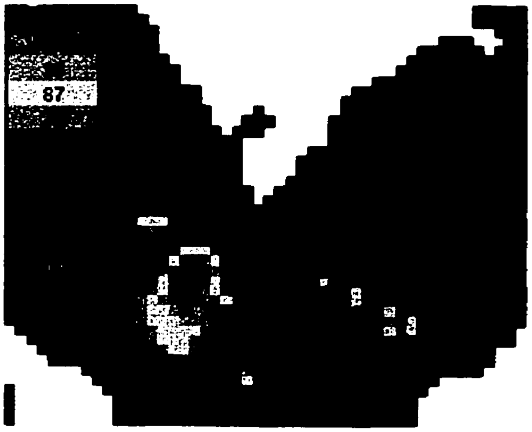


Subject #3
Back
Seat B

Subject #4
Cushion
Seat B



Subject #4
Back
Seat B

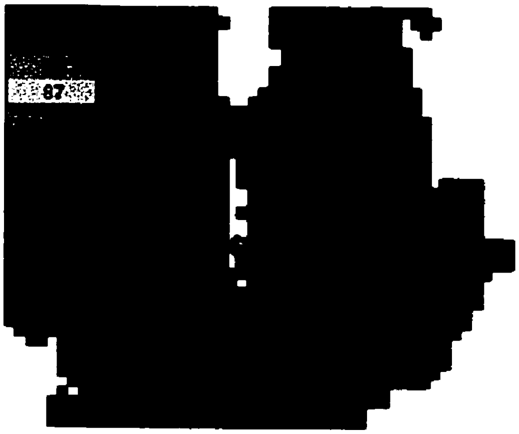


Subject #5
Cushion
Seat B

Subject #5
Back
Seat B

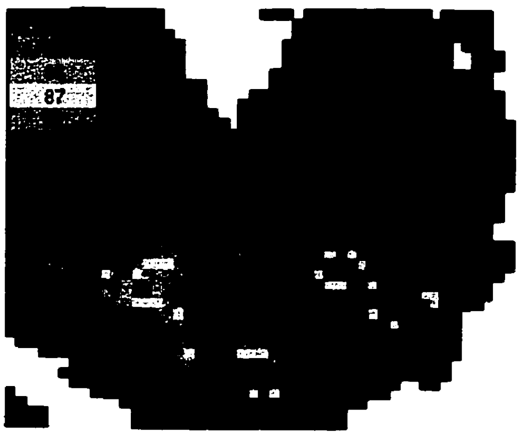
Subject #6
Cushion
Seat B

Subject #6
Back
Seat B



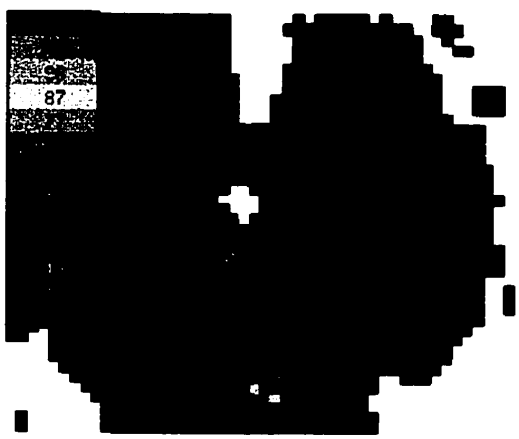
Subject #7
Cushion
Seat B

Subject #7
Back
Seat B

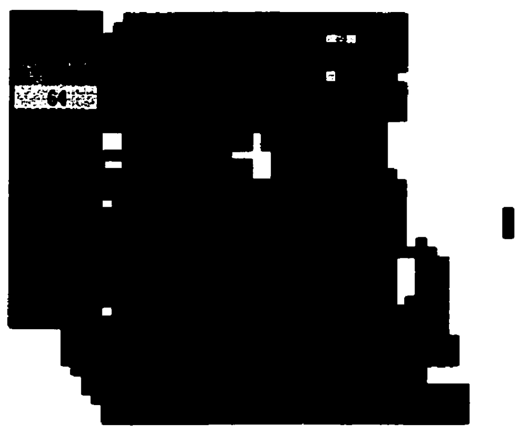


Subject #8
Cushion
Seat B

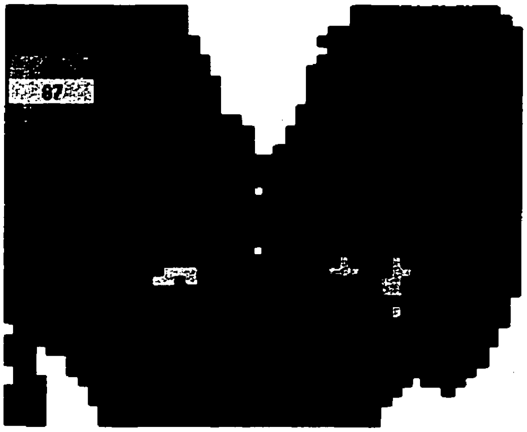
Subject #8
Back
Seat B



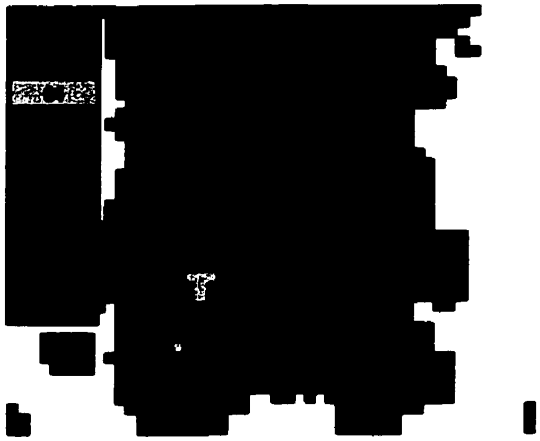
Subject #9
Cushion
Seat B



Subject #9
Back
Seat B



Subject #10
Cushion
Seat B



Subject #10
Back
Seat B

Subject #11
Cushion
Seat B

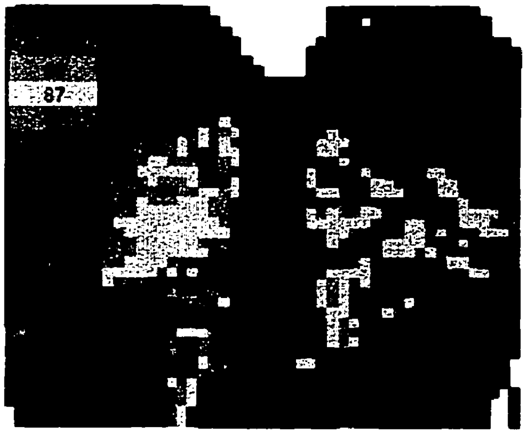
Subject #11
Back
Seat B

Subject #12
Cushion
Seat B

Subject #12
Back
Seat B

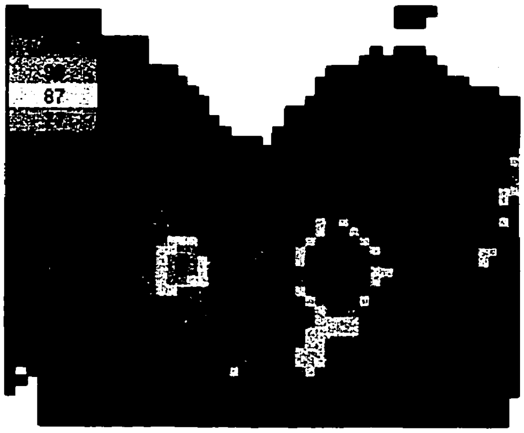
Subject #1
Cushion
Seat C

Subject #1
Back
Seat C

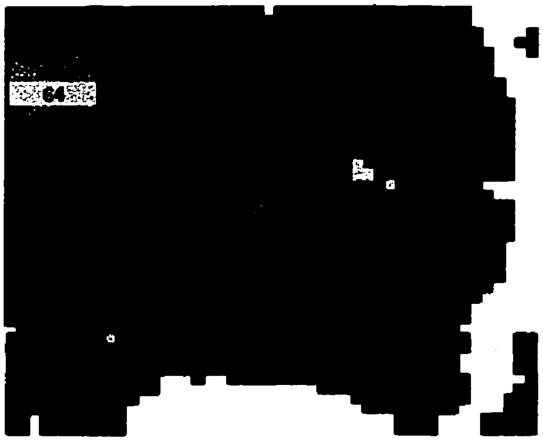


Subject #2
Cushion
Seat C

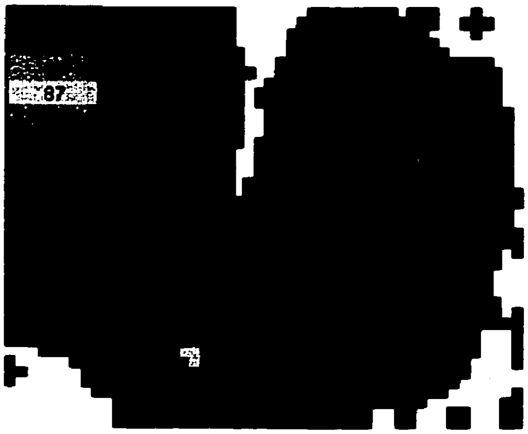
Subject #2
Back
Seat C



Subject #3
Cushion
Seat C



Subject #3
Back
Seat C



Subject #4
Cushion
Seat C

Subject #4
Back
Seat C

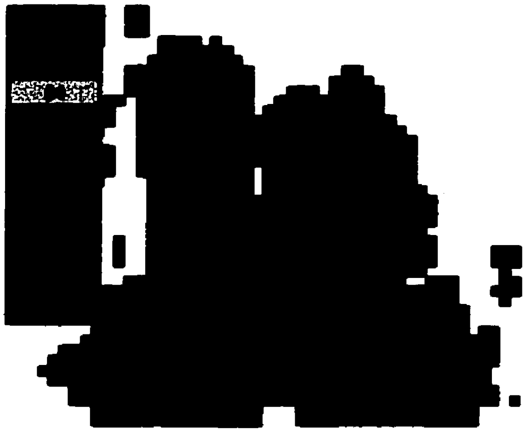
Subject #5
Cushion
Seat C

Subject #5
Back
Seat C

Subject #6
Cushion
Seat C

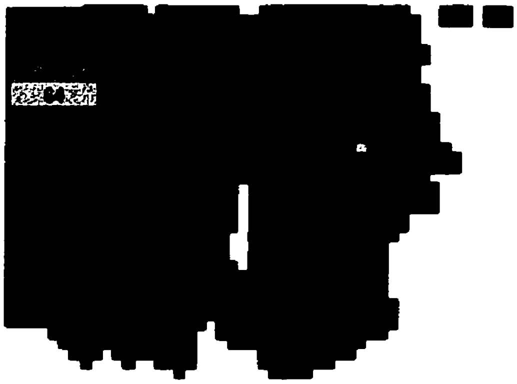
Subject #6
Back
Seat C

Subject #7
Cushion
Seat C

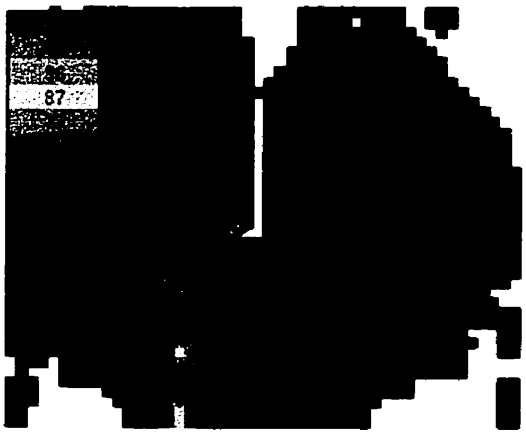


Subject #7
Back
Seat C

Subject #8
Cushion
Seat C



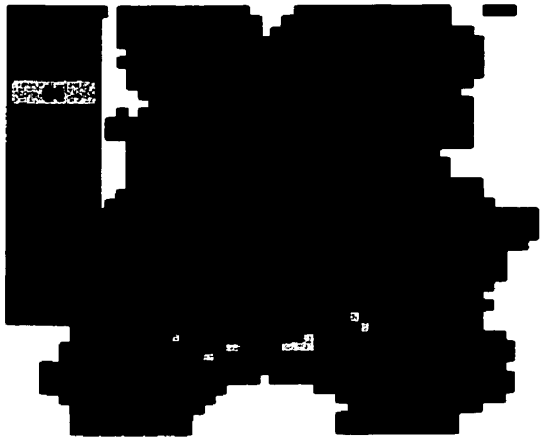
Subject #8
Back
Seat C



Subject #9
Cushion
Seat C

Subject #9
Back
Seat C

Subject #10
Cushion
Seat C

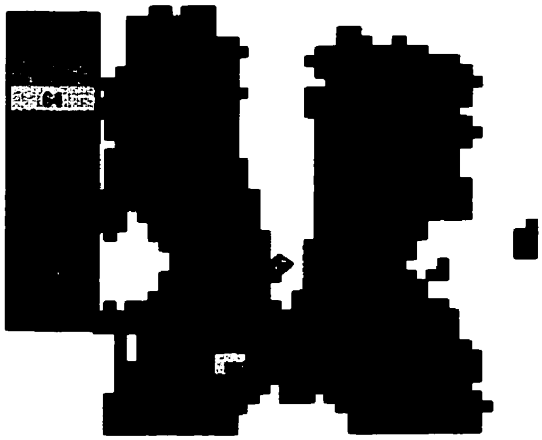


Subject #10
Back
Seat C

Subject #11
Cushion
Seat C

Subject #11
Back
Seat C

Subject #12
Cushion
Seat C



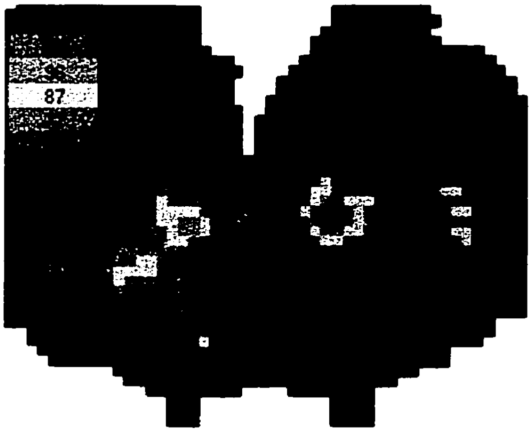
Subject #12
Back
Seat C

Subject #1
Cushion
Seat D

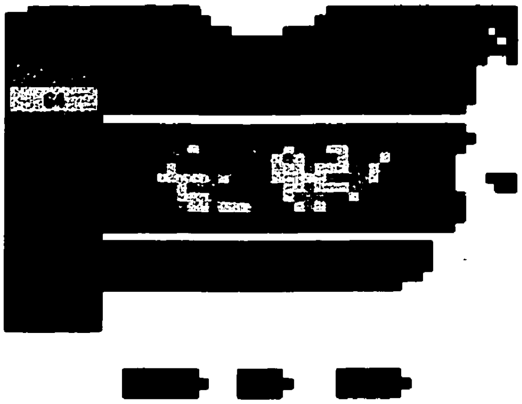
Subject #1
Back
Seat D

Subject #2
Cushion
Seat D

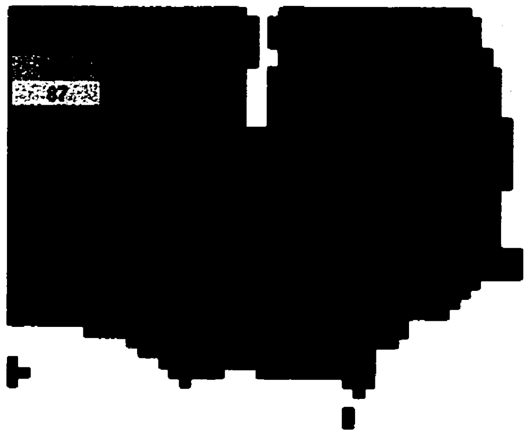
Subject #2
Back
Seat D



Subject #3
Cushion
Seat D

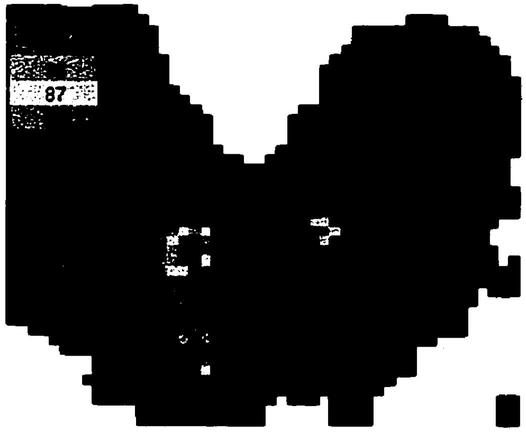


Subject #3
Back
Seat D

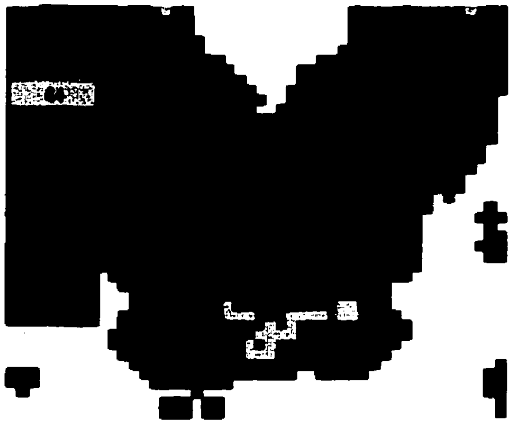


Subject #4
Cushion
Seat D

Subject #4
Back
Seat D

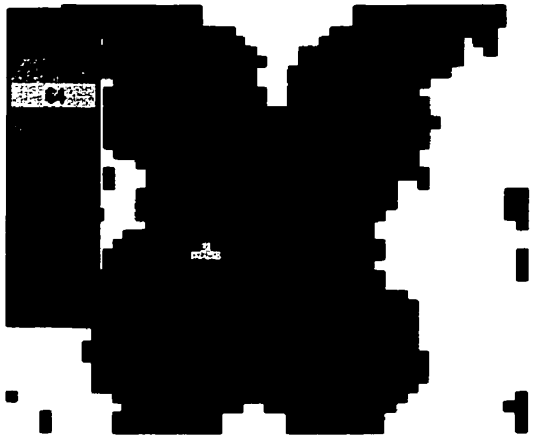


Subject #5
Cushion
Seat D



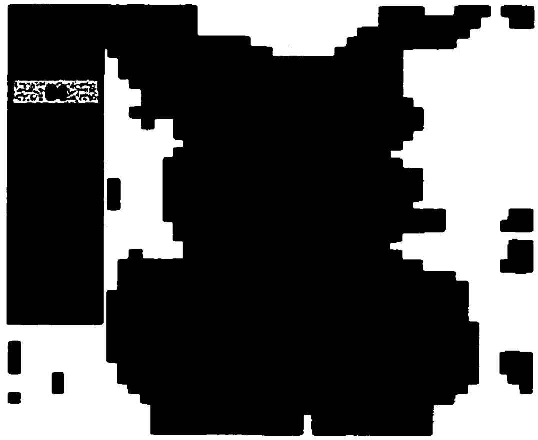
Subject #5
Back
Seat D

Subject #6
Cushion
Seat D

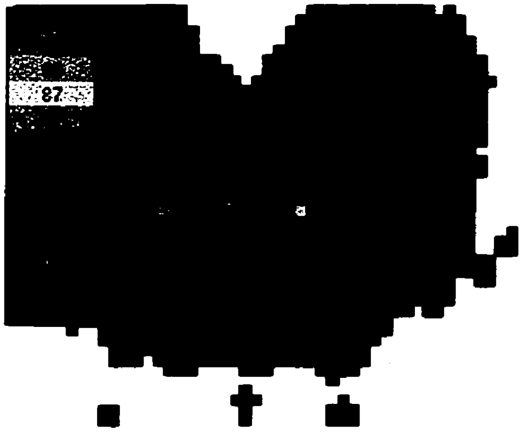


Subject #6
Back
Seat D

Subject #7
Cushion
Seat D

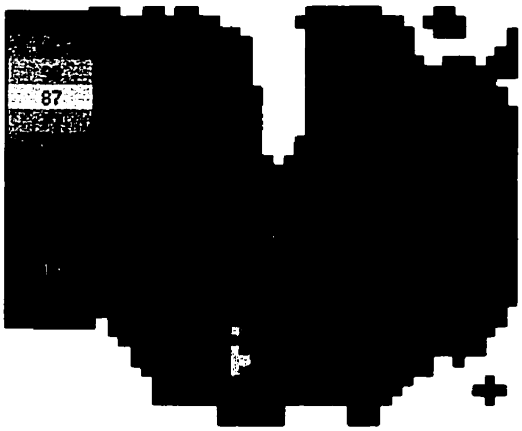


Subject #7
Back
Seat D



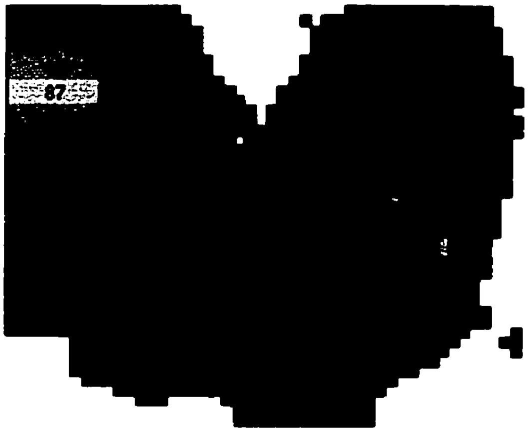
Subject #8
Cushion
Seat D

Subject #8
Back
Seat D



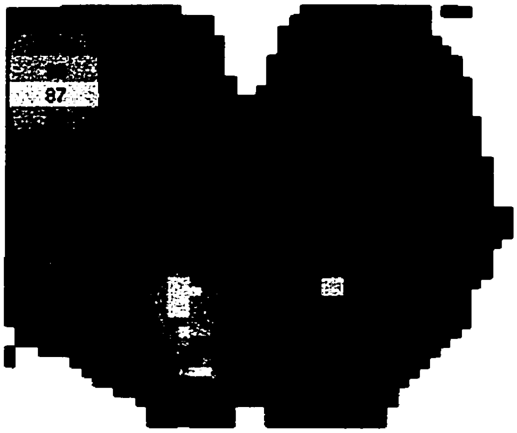
Subject #9
Comfort
Seat D

Subject #9
Comfort
Seat D



Subject #10
Cushion
Seat D

Subject #10
Back
Seat D



Subject #11
Cushion
Seat D

Subject #11
Back
Seat D

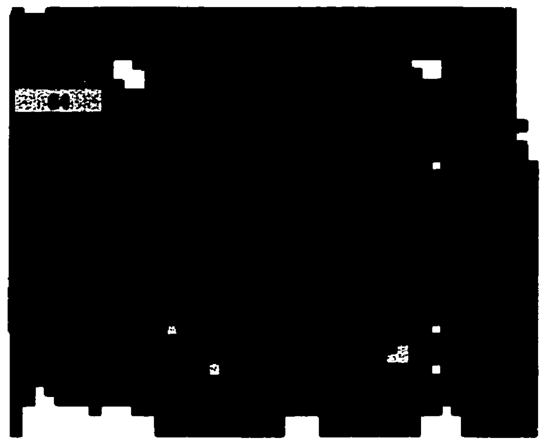
Subject #12
Cushion
Seat D

Subject #12
Back
Seat D

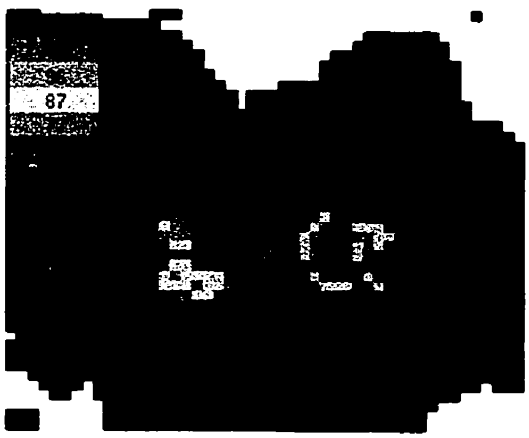
Subject #1
Cushion
Seat E

Subject #1
Back
Seat E

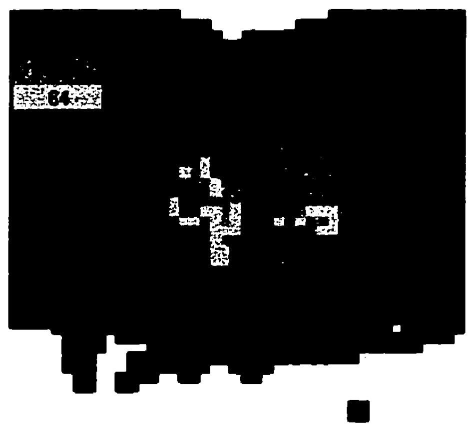
Subject #2
Cushion
Seat E



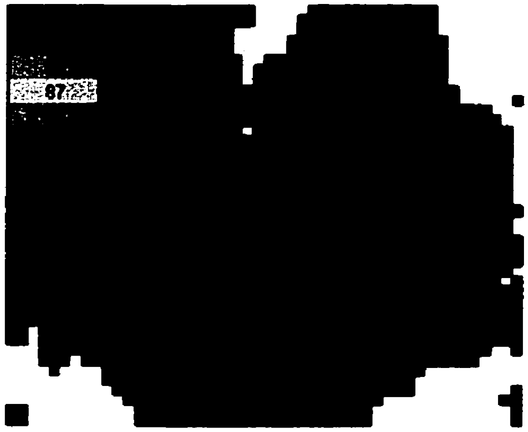
Subject #2
Back
Seat E



Subject #3
Cushion
Seat E

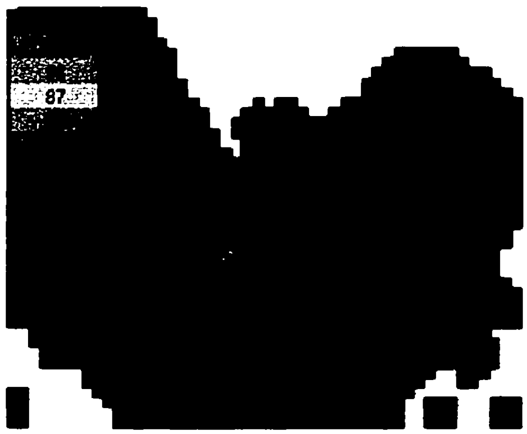


Subject #3
Back
Seat E

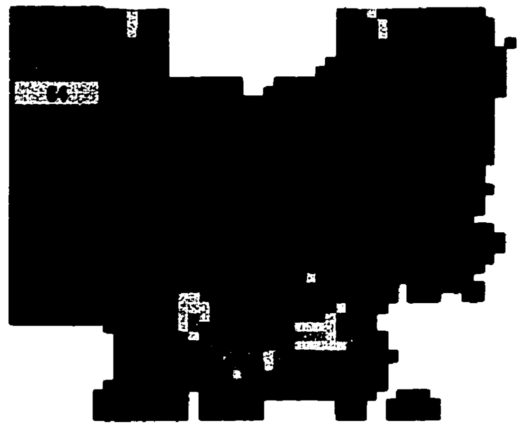


Subject #4
Cushion
Seat E

Subject #4
Back
Seat E



Subject #5
Cushion
Seat E

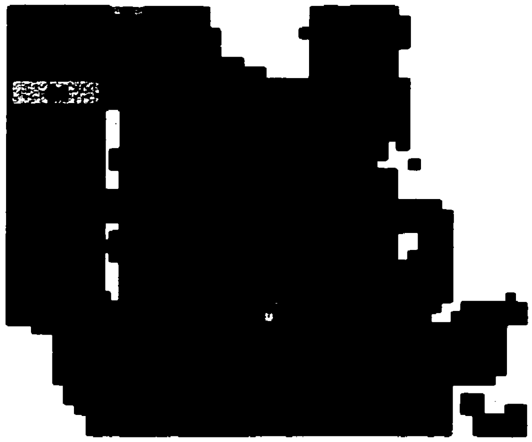


Subject #5
Back
Seat E

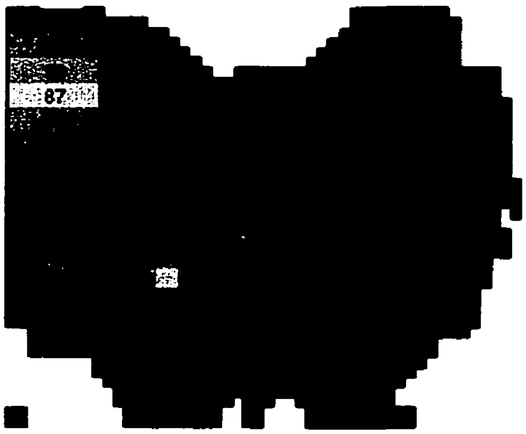
Subject #6
Cushion
Seat E

Subject #6
Back
Seat E

Subject #7
Cushion
Seat E

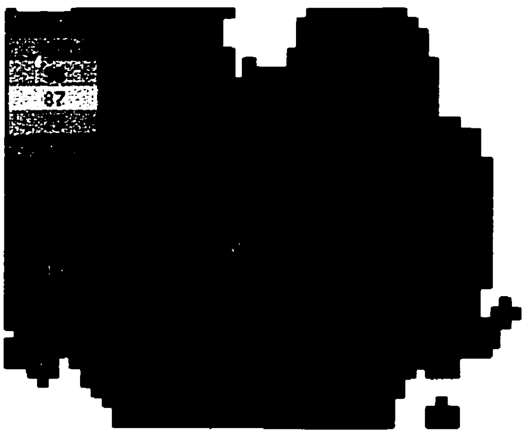


Subject #7
Back
Seat E



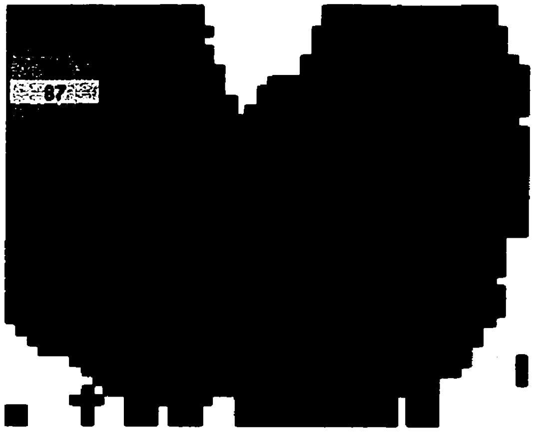
Subject #8
Cushion
Seat E

Subject #8
Back
Seat E



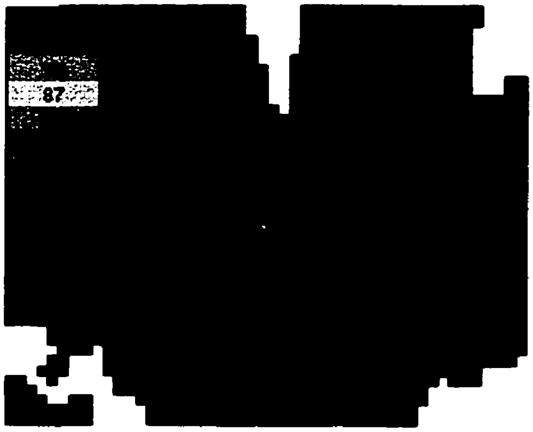
Subject #9
Cushion
Seat E

Subject #9
Back
Seat E

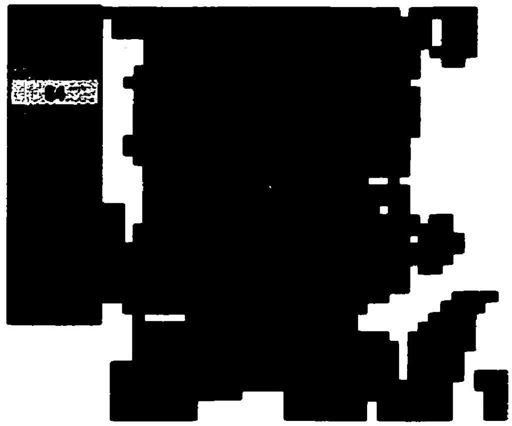


Subject #10
Cushion
Seat E

Subject #10
Back
Seat E



Subject #11
Cushion
Seat E



Subject #11
Back
Seat E

Subject #12
Cushion
Seat E

Subject #12
Back
Seat E

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VITA AUCTORIS

Mike Kolich was born in 1972 in Windsor, Ontario, Canada. He attended high school in Windsor and graduated in 1991. From there he went on to the University of Windsor where he obtained two degrees. He is currently a candidate for a Doctor of Philosophy degree in Industrial & Manufacturing Systems Engineering at the University of Windsor. He plans to graduate in October of 2000.