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Driver Discomfort:
Prevalence, Prediction and Prevention

by

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Abstract

This research is concerned with exploring the relationship between car driving and musculoskeletal troubles and following on from this investigating methods which could aid the automotive industry in the design and evaluation of car seats. The thesis is divided into two parts.

Part I describes the development and results of an epidemiological survey undertaken with data obtained from two sample groups. Study 1 was an interview survey (based on the Nordic Questionnaire) of 600 members of the British public, randomly selected within the strata of age and gender. Study 2 used the same interview, but with two carefully chosen groups of police officers (n=200). The results indicated that car drivers (especially those who drove as part of their job) appeared to be at risk in terms of reported discomfort and sickness absence due to low back trouble. Evidence from this and other studies has also indicated that drivers with the most adjustable driving packages may benefit in terms of both reduced discomfort and reduced sickness absence. This provided the background for the subsequent research in Part II and some impetus for car manufacturers to consider health issues in the design of car workstations.

Part II involved a series of three experiments designed to investigate methodologies which could be used by manufacturers to predict car seat discomfort. The literature was reviewed to identify suitable predictive techniques which would be robust enough to provide information to the automotive industry in 'real world' situations. The technique of interface pressure measurement had already generated interest in some seat manufacturers and was therefore selected for investigation. As a result of the findings in experiment 1, established guidelines for a comfortable driving posture may need to be modified. The other two experiments were designed to create discomfort in subjects firstly by varying foam hardness and secondly by varying posture. A clear, simple and consistent relationship between interface pressure and discomfort in realistic driving situations was not identified. Future studies using this technique should provide information regarding such factors as gender, the body mass index, anthropometric data, posture and foam hardness due to the confounding nature of these variables.

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Chapter 1 Introduction

1.1 Background to the Project

The Vehicle Ergonomics Group (VEG) based at Loughborough University of Technology has been involved in research in the area of vehicle seating since 1981. Low back discomfort was frequently reported in their studies, some cars notably worse than others. Research by VEG (Porter et al, 1992) involving a survey of 1000 drivers at several motorway service stations in England found that 25% of all drivers and 66% of all business drivers were suffering from some low back discomfort at the time of the interview. There also appear to be more serious consequences of driving as part of work such as the increased risk of acute herniated lumbar disc as found by Kelsey and Hardy (1975). The latter study and the research experience of VEG lead to interest in the question of whether there were associated health risks with car driving (i.e. musculoskeletal troubles). Generally, studies were scarce and further evidence was required to ensure that car manufacturers, employers and of course drivers, treated driving more seriously with regard to its potential contribution to musculoskeletal troubles, especially low back pain.

The financial costs of low back pain are direct medical costs, permanent disability awards and temporary disability payments as well as the costs incurred as a result of lost productivity and replacement training (Spengler et al, 1986). If driving was shown to be linked to musculoskeletal troubles, it follows that any methods which could aid the automotive industry with the design and evaluation of their driving packages in the first place could have a positive effect on the prevention of such high costs. VEG has already established methods for evaluating the driver's workstation (seat comfort, reach, vision) using subjective data. It was apparent from this work that there were vast differences between vehicles, for example, a driver workstation which was the most comfortable of three comparable cars after 15 minutes may not be the most comfortable after a few hours. Their road trials however often took several months to complete (i.e. selecting subjects, running the 2.5 hour driving trials and analysing the data) and were often carried out when the car was almost ready for production. Predictive techniques providing car seat designers and manufacturers with rapid information early on in the design process would have obvious advantages, which could be passed on to the consumer in the form of high quality seating systems minimising discomfort. Any predictive technique would need to be robust enough to provide information to the automotive industry in 'real world' situations i.e. using a variety of subjects with different car seat designs. The technique of interface pressure measurement had already generated interest in seat manufacturers and was therefore thought suitable for more thorough investigation.

In summary it was realised that there was a need to:-

1. understand more fully the problem of driver related discomfort in order to promote greater awareness;
2. assist the automotive industry in the design and evaluation of car seats and the driving workstation.

These broad aims were formulated into the ergonomics contribution to a research proposal that was submitted to and consequently accepted by the Brite Euram European Initiative. The work also formed the basis of this PhD thesis.

1.1.1 The Brite Euram Project (Seat Evaluation and Design)

Loughborough University was one of seven European based partners involved in a Brite Euram research task whose joint objective was to produce an engineering platform to support the design, evaluation and manufacture of automotive seat systems which were of high quality and performance, safe, utilised recycling technologies and which were acceptable to the consumer. The data collected from the project will also support national and international standards regarding these issues. The partners in the joint consortium were:-

1. Centro Ricerche Fiat SCpA, Turin.
2. Lear Seating, Italy (previously Sepi SpA).
3. Courtaulds Textiles Automotive Products, Manchester.
4. Lear Seating GmbH, Germany.
5. Technische Universitat Berlin, Der Prasident, Berlin.
6. Loughborough University of Technology.
7. University of Southampton.

Loughborough's contribution was the subject of 'Ergonomics and Postural Comfort'. The consortium met every six months, where each partner presented their findings to date and submitted a report. This gave a unique opportunity for direct communication with the automotive industry.

1.2 Objectives of the Project

1. To explore the relationship between driving and musculoskeletal troubles and identify some of the major causal factors of driver related discomfort (Part I).

2a. To review the literature for methods of rapidly quantifying, within the context of a specific design, car seat comfort / discomfort using subjective and objective methods (Part II).

2b. To evaluate the technique of pressure distribution as a predictive measure of car seat comfort / discomfort (Part II).

1.3 Structure of the Thesis

This thesis is divided into the two main study areas. It begins with a literature review of driving and musculoskeletal troubles (Chapter 2), the rationale behind Part I (Chapter 3) and development of the questionnaire (Chapter 4), followed by the description and discussion of the two surveys conducted (Chapters 5, 6 and 7). Part II of the thesis presents a literature review of predictive methodologies for seat comfort leading to the experimental rational (Chapter 8) and the development of the equipment (Chapter 9). Three experimental studies are then presented (Chapters 10, 11 and 12) with an overall discussion of the results (Chapter 13). The final chapter presents the conclusions and future work for both parts of the thesis (Chapter 14).

Part I

The Survey Work

Chapter 2 Driving and Musculoskeletal Troubles

2.1 Introduction

In order to achieve Objective 1 stated in Chapter 1.2, it was necessary to review the literature for existing studies examining musculoskeletal problems and driving. The reasons why driving could potentially lead to such problems are then considered by discussing in detail the seated posture and some car design aspects which exacerbate these problems.

2.2 Epidemiological Studies, Driving and Back Pain

Epidemiological studies examining the relationship between car driving and back pain or other musculoskeletal disorders are relatively few which is perhaps indicative of the difficulties of conducting such studies. Rey (1979) reviewed the literature concerning the health effects of hazards in the workplace, for example vibration and noise. The multifactorial nature and confusing number of confounding variables regarding workplace disorders prompted him to suggest an approach based on multiple relationships and influences. He also advised that in order to be of importance any associations should be strong; repeatedly observed; the underlying causes specific; and the degree of exposure and time interval should relate to the effect. No studies were found which met all these criteria. In contrast, a more simplistic association between design and disease was suggested by van Wely (1970): He devised a list of 'bad postures' and hypothetical sites of pain, stiffness or other symptoms based on a knowledge of functional anatomy and physiology. For example, sitting without a lumbar support would cause symptoms of low back pain. This assumption however took no account of variables such as age, sex, stress, lifestyle and motivation which may also have had an effect on symptoms in the lumbar region.

Driving as a task involves prolonged sitting, vibration, perhaps periodic lifting and it may also be that professional drivers smoke more heavily than the general population; these all illustrate the difficulties of looking at the effects of specific factors in isolation. Many authors, for example Kelsey and Hardy (1975), Frymoyer et al (1983) and Troup (1978) do agree that the relationship between driving and the incidence of musculoskeletal troubles does warrant further investigation.

Kelsey and Hardy (1975) carried out an important study which was concerned with the causes of herniated lumbar disc leading to some important findings in this area. The same study is also described in Kelsey (1975) and Kelsey and Ostfeld (1975). Interviewers saw patients who attended x-ray departments in the New Haven District for lumbo-sacral x-rays over the two year period between June 1971 and May 1973. They were questioned about their symptoms and diagnostic tests were also carried out to determine sufferers of acute herniated lumbar disc. All cases (and controls) in the study were patients aged 20-64 and were divided into groups as follows:-

1. Surgical cases of acute herniated lumbar disc.
2. Probable cases of acute herniated lumbar disc.
3. Possible cases of acute herniated lumbar disc.

These cases were then matched individually to a control group of the same sex and approximately the same age, who attended the x-ray department for conditions not related to the spine, giving a total of 217 pairs (89 females and 128 males) for comparison. They were also compared with a second control group consisting of individuals who had the symptoms of acute herniated lumbar disc for less than one year and who did not fit into the classification of groups above. There were 494 controls (225 females and 269 males). The main findings relevant to this study are:-

1. Using their data regarding the occupational history of these males, they found that comparing cases to matched controls at the time the symptoms developed, if the case had a job where he spent more than half his time in a motor vehicle he was 2.75 times more likely to develop an acute herniated lumbar disc. If cases were compared to unmatched controls the estimated relative risk was similar at 3.14

2. Again, comparing cases to matched controls it was found that if a male has ever had a job where he spent more than half his time in a motor vehicle, he was 2.13 times more likely to develop an acute herniated lumbar disc than a male who has not. Comparing cases with unmatched controls an

individual was 1.82 times more likely to develop an acute herniated lumbar disc if they **ever** had a job involving driving for more than half their time. Police patrol drivers and salesmen were noted as being at particular risk but were not represented in large enough numbers for statistical significance.

3. Truck drivers appeared to be at particularly high risk and were estimated as being 4.67 times more likely to develop an acute herniated lumbar disc than males who were not truck drivers. A male who has ever been a truck driver was 2.86 times more likely (for cases and matched controls) and 1.59 times more likely (for cases and unmatched controls) to develop an acute herniated lumbar disc.

The study was not designed to look specifically at driving nor was driving felt to be a risk variable yet it appeared as a factor in two separate parts of the questionnaire, reducing the likelihood that this association could have occurred by chance. Also sampling from an outpatient population avoided some of the problems of the 'healthy worker effect' (discussed in Chapter 3.3.1). The issue that it was the prolonged sitting which was damaging, whether in a motor vehicle or not was also addressed by the fact that 'the relative risk for sitting while driving was nearly twice as high as that for sitting in a chair regardless of the type of chair'. One criticism of this study however was the lack of a control group from the general population weighting the study towards individuals who attended hospitals, specifically x-ray departments. The study was also concerned with the causes of acute herniated lumbar disc and not back symptoms in general. Nevertheless, the results had implications for other forms of back pain and provided epidemiological evidence of the possible effects of prolonged driving. The vast majority of individuals complaining of low back pain do not require surgical or hospital intervention and therefore these results could just be the 'tip of the iceberg'.

A questionnaire survey of 1221 men attending a Family Health Care Unit between 1975 and 1978 was carried out by Frymoyer et al (1983). They identified vibration, lifting and exposure to motor vehicles (in terms of hours per week) as significant risk factors in low back pain. In the study subjects were divided into three groups: no low back pain, moderate low back pain and severe low back pain. Following on from this work Damkot et al (1984) conducted a study where complete medical examinations, psychological and biomechanical analyses and detailed questionnaire surveys of the workplace environment were carried out on a representative sample of 303 of the 1221 men. The distribution of symptoms in these men was similar to that in Frymoyer et al's (1983) survey of 1221 men. The questionnaire survey of the workplace detailed information on task frequency, lifting postures, stretching, bending, twisting, equipment used etc., and if symptoms of back pain occurred subjects were asked to identify the situations to which they felt the onset could be attributed. Comparing the three pain groups the following variables were found to be related to a greater risk of low back pain symptoms; increased automobile exposure (in terms of the length of time the individual had been driving); the number of times getting in/out of a vehicle; the number of lifts each day and pulling heavy weights. Truck driving exposure was associated with increased severity of low back pain symptoms complimenting the work of Kelsey and Hardy (1975) described above. The presence or absence of full or partial back supports were related to back pain symptoms and their observations confirm the importance of preventative strategies such as lumbar supports, arm supports, and seat inclination. However, all the relationships found between occupational tasks and symptoms should be viewed with caution as symptom severity could relate to many other psychosocial issues such as compensation claims, poor motivation and job satisfaction which were not addressed in this study.

A postal questionnaire survey of low back pain symptoms and prevalence was carried out by Riihimaki et al (1989). Three occupational groups were compared; 852 machine operators (541 longshoremen and 311 earth movers) exposed to low-frequency whole-body vibration; 696 carpenters (dynamic physical work) and 674 office workers (sedentary work). The lifetime prevalence of low back trouble was very high in all of the groups; 90% for machine operators and carpenters and 75% in office workers. This could be explained by the poor response rate (67-76%) and the likelihood that the sample was biased with predominately those with back trouble replying. This may even affect the comparison between groups as perhaps sedentary workers could continue to work with low back trouble whereas machine operators with back trouble may not have been able to. Using multivariate regression analysis, annual car driving was not found to be a risk factor for the occurrence of 'sciatic pain', 'lumbago' or 'other low back pain' in the whole sample. Machine operating, age, severe back accidents and twisted or bent postures however did prove to be risk indicators for sciatic pain. There was a positive relationship between annual car driving and the prevalence of sciatic pain in office workers but a negative correlation in machine operators. It is difficult to speculate from the paper why this should occur. The range of annual mileage was not given but could be assumed to be lower than that of a professional driver as the categories used were '<5,000 km', '5,000-15,000 km' and '>15,000 km'. It could also be argued that the low frequency whole body vibration experienced by machine operators was similar to car driving and therefore professional drivers may be at some risk.

Walsh et al (1989) sent postal questionnaires to a random sample of 545 adults in the south of England in an attempt to examine the associations between occupational activities and low back pain. The questionnaire was returned by 436 subjects (200 males, 236 females) who completed questions regarding their full occupational history and indicated whether these jobs involved standing, walking or sitting for more than two hours, driving a car or van for more than four hours, tractor driving, truck driving, lifting weights of more than 25 kg or using hand held vibrating machinery. Subjects were then asked to detail their history of back pain, for example commencement of symptoms, 12 month period prevalence and the affect on their daily living skills. The lifetime prevalence of low back pain was found to be 64% of men and 61% of women. The strongest association was found between heavy lifting and low back pain for both men and women (14% estimated as attributable). They also found that driving a car for more than four hours a day was associated with low back pain but for the sample of men only (4% estimated as attributable). However, it was found that the number of women who reported driving a car for more than four hours a day was small. The authors concluded that these results add more evidence to the case implicating driving as a risk factor for low back pain. The effect of jobs which involved sitting for more than two hours were also examined, but the results were not significant, except in women with prolonged exposure. The high rate of return of the questionnaire from the random sample suggests that responses were not just from sufferers of low back pain. The only real criticism of this study concerns the possible inaccuracies in recalling the dates etc., involved in job changes and the onset of symptoms of low back pain, which could effect the accuracy of the risks given in their paper.

Pietri et al (1992) carried out a more recent and extensive study of a random sample of commercial travellers (1376 males, 343 females) from towns in France. Physicians used a standardised approach to carry out short (10-20 minutes) interviews with questions regarding the lifestyle (smoking, sports), work (hours driving, lifting and standing), general health problems and psychological problems (derived from Langner, 1962) of the workers as part of their annual medical examination. The interviews were carried out at the beginning of the study (cross sectional study, n=1709) and with some of the same workers 12 months later (longitudinal study, n=627 for the analysis). In the cross sectional study subjects with low back pain were compared to those without, and the risks of low back pain were significantly associated with driving more than 20 hours a week. Other factors in this part of the study associated with low back pain were psychosomatic factors, age (males only), smoking, car seat comfort, carrying loads and standing. Considering the longitudinal study, the incidence of low back pain during the following 12 months was associated with the comfort of the car seat, driving between 10 and 20 hours a week and having three or four psychosomatic symptoms (for example headaches, irritability or insomnia). Smoking, age, carrying loads and standing were not found to be predictors of low back pain. The fact that the number of hours driving and car seat comfort were risk factors for the prevalence of low back pain supports their hypothesis of driving as a causal risk factor for low back pain. As with the Kelsey and Hardy (1975) study however, the lack of a true control group i.e. non-exposure / low exposure to driving could be a criticism of their work, but the fact that a relationship was found without extremes of exposure could add further weight to their results. Also, the sample of commercial travellers did not include drivers from the larger companies (who would have their own physician) or self employed drivers with no annual medical examination, however there is no reason to suppose that these drivers were any different to those in the sample. Finally the term 'low back pain' was used with no indication of whether the symptoms were severe or not and whether sickness absence resulted. Consequently the range of severity of the symptoms could be huge.

An interview survey of 1000 car drivers selected at random was carried out by Porter et al (1992) at three motorway service stations in England. They were questioned about driving times and distances and the specifications of their vehicles, immediately on leaving their cars. Drivers completed discomfort / comfort ratings of 20 body areas using a modified version of the 'body map' idea of Corlett and Bishop (1976) and an overall discomfort / comfort rating scale was also used. They found that driver discomfort was more prevalent with increased time driving. When the car had a manual gearbox, 72% of drivers rated their overall body comfort as 'comfortable' or 'very comfortable' compared to 88% of drivers of cars with automatic gearboxes ($p<0.001$). Increasing discomfort was significantly associated with drivers of cars with no seat height, tilt or lumbar support adjustments ($p<0.001$ in all cases). It can be assumed with these cars that the individual driver was less able to adjust the seat to obtain his or her optimum driving posture. Discomfort was reported in at least one body area by 53% of drivers and the major areas of reported discomfort were the low back (25%) and the neck (10%). The discomfort / comfort data interpretation however does have limitations, as there was not sufficient time for the collection of information regarding the driver's stress, mood etc., which may have influenced the subjective ratings. Additionally, little was known about other factors which may influence the discomfort experienced such as lifestyle and occupational demands, for example, lifting.

Following on from this study Wood and Porter (1992) carried out an almost identical survey of 200 drivers of four popular fleet cars on the British market. It was found that 64.5% of all drivers reported discomfort in at least one body area, the most common being the low back (49.5%) and the mid back (12%). Increased time driving that day was positively correlated with overall body discomfort, neck, lower back, right shoulder, right upper arm and buttock discomfort. More drivers rated their overall body comfort as 'very comfortable' or 'comfortable' when their vehicle had steering wheel adjustment (height or tilt, in or out), power steering, seat height adjustment and lumbar support adjustment. A significant positive relationship was found between motorway driving that day and low back discomfort. Motorway driving accounted for the highest number of minutes that day (mean 150 minutes compared with 29 minutes town driving), therefore the subjects were sitting in relatively fixed postures. The study supported the view that postural discomfort does occur in those who drive for long periods of time, but again little was presented about other factors which may influence discomfort.

2.2.1 Epidemiological Studies and Back Pain

There is a huge amount of literature on the subject of low back pain. In this section the epidemic of back pain in Western society is very briefly discussed together with the costs incurred by this condition.

"At some stage in their life, 80% of the human race will experience low back pain." (Waddell, 1987).

Waddell (1987) also reports from the work of other authors that as well as the actual physical abnormality, the clinical assessment of back pain depends on the patient's subjective report which is influenced by the individual's attitudes, psychological stress, the restrictions on their activities and general illness behaviour. In his review of the literature he concludes the following:-

1. Low back pain is a universal condition and may from one perspective be regarded as normal.
2. Low back disability, as opposed to low back pain, seems to be a recent Western epidemic which is not explained by any demonstrable change in the physical disorder.
3. Conventional medical treatment has largely failed and the role of medicine in the present epidemic must be re-examined. He suggests that its management should change to involve active restoration of function and not the negative philosophy of 'rest for pain'.

In terms of cost, low back pain causes the greatest problem with time off work and health care management, although most individuals do not seek medical treatment (Waddell, 1987). As few as 2-5% of individuals actually file claims for compensation

(Spengler et al, 1986). In their study of 4,645 injury claims at the Boeing Company, Washington, 20% of the total claims were for back injuries but they accounted for 41% of the total cost for all injuries. Interestingly, 90 out of the 900 back injury claims, accounted for 79% of the total cost of all back injuries. They concluded that there was a need to control or prevent this small number of high-cost back injuries.

Similarly, Pheasant (1992b) hypothesised that the pattern of occurrence of musculoskeletal troubles could be described by a pyramid (Figure 1). At the bottom were a large proportion of people (prevalence 70-90%) who suffer task related musculoskeletal trouble but do not complain very much. A minority of these develop serious clinical conditions but between these extremes was a continuum of problems many of which could be prevented by redesign of the work or workplace. This could be said to include the driving workstation.

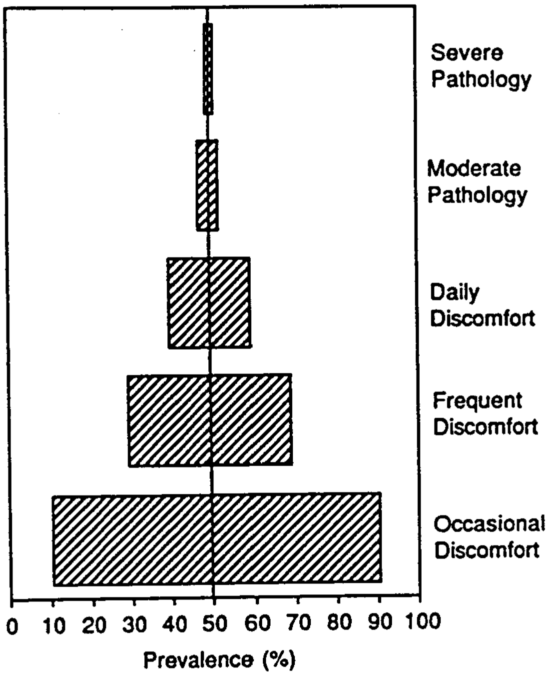


Figure 1. The distribution of work related musculoskeletal symptoms (Pheasant 1992b).

2.2.2 Discussion of the Epidemiological Studies

There is concern about the current epidemic of low back pain and the costs incurred in its management. There are also an increasing number of authors whose research adds weight to the implication of prolonged exposure to car driving as being a risk factor for low back pain. It has been reported as a risk factor for acute herniated lumbar disc in males (Kelsey and Hardy, 1975) and as a risk factor for low back pain in American males (Frymoyer et al, 1983 and Damkot et al, 1984), British males (Walsh et al, 1989) and French commercial travellers (Pietri et al, 1992). Interestingly the risks have been noted to be higher for similar exposures i.e. driving for more than half the working day (Kelsey and Hardy, 1975), more than 4 hours a day (Walsh et al, 1989) and more than 20 hours a week (Pietri et al, 1992). Also Porter et al (1992) and Wood and Porter (1992) found that driver discomfort was more prevalent with increased time driving and that generally less discomfort was reported in drivers of cars with more adjustable features such as steering wheel adjustment or a lumbar support. Frymoyer et al's (1983) work also confirmed the importance of preventative strategies such as lumbar supports, arm supports and seat inclination.

In the paper by Troup (1978) however, it was concluded that at that time there was not enough epidemiological evidence to state that the postural stress of prolonged sitting alone was a recognised cause of back trouble in drivers. The work of the aforementioned body of researchers now begins to challenge this statement.

2.3 Driving Posture and Discomfort

Driving as a task involves prolonged sitting, a fixed posture, vibration and muscular effort, any of which individually could lead to musculoskeletal troubles. In this section posture is defined and then the driving posture is discussed in relation to why it may have an effect on musculoskeletal troubles and discomfort. Although the factors discussed in this section for example pelvic rotation and vibration, may be interrelated, they are reported under separate headings for convenience.

"Posture is usually defined as the positions of the trunk, head and the limbs in relation to each other and is expressed in terms of the angles at major joints of the body" (Asatekin, 1975).

The efficiency of a posture from a simple biomechanics view point can be determined by the degree to which it loads the skeleton and the postural muscles. Postural stress is a result of gravitational (and other forces) acting on the body and the forces required by the muscle activity to maintain any particular posture (Troup, 1978), the stress being greater in sitting than standing. Consequently even the most comfortable posture can be fatiguing over time leading to muscular fatigue. Chronic strain over long periods and its contribution to the accelerated onset of degenerative diseases such as osteoarthritis is difficult to assess, but Grandjean (1984) supported the view that postural strain was associated with increased risk of inflammation of the joints and tendon sheaths, degenerative diseases and disc problems.

2.3.1 Pelvic Rotation and Intervertebral Disc Pressure

In the sitting posture, backward rotation of the pelvis flattens the lumbar lordosis. This rotation is limited by the length of the posterior thigh muscles (hamstrings) which is in turn also affected by knee flexion. The lumbar curve could be actively maintained by contraction of the latissimus dorsi and the sacrospinalis muscles but this is very tiring. Unless the backwards rotation is controlled (i.e. with a correctly designed seat and backrest), the resultant wedging pressure on the intervertebral discs partially displaces them causing them to protrude posteriorly and stretch the posterior longitudinal ligament over the disc (Figure 2). In fact, posterior protrusion of a degenerated 4th and 5th lumbar intervertebtal disc with consequent stretching of the posterior ligament over the disc is a common cause of low back pain (Keegan, 1953) especially with increasing age. Prolonged sitting in a poorly designed car seat therefore flattens the lumbar lordosis increasing pressure within the discs, strains the spinal ligaments and gluteal muscles and increases thoracic kyphosis providing a source of discomfort. This slouched posture could be exacerbated by design features such as a sunroof which reduces the headroom available in the car and additionally results in increased cervical flexion, a source of neck discomfort for the driver (Porter et al, 1992). Car seats are also low, having the effect (especially in the taller driver) of further increasing hip flexion and backwards rotation of the pelvis, and flattening the lumbar lordosis, potentially leading to discomfort.

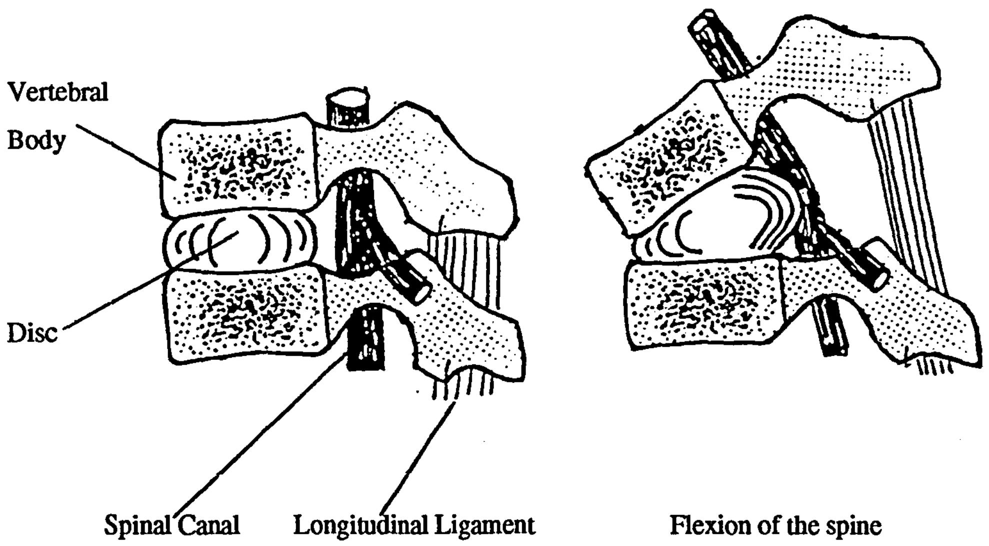


Figure 2. Diagram to show a section of the spine and the effect of flexion.

2.3.2 Vibration

The high incidence of back pain amongst professional drivers of vehicles with a high vibration magnitude, for example tractors and trucks, has been well documented (Kelsey, 1975; Burton and Sandover, 1987; Troup, 1978). Vibration levels in cars are generally low due to improved suspension systems and road quality, however the driver's spine is subject to vertical impact with an uneven road surface, for example pot holes, and also from sudden starting and stopping. If the spine is inadequately supported or the driver is leaning forward the effect on the spine is more damaging. Troup (1978) recognised that poor posture and vertical vibration in the range of 4 to 8 Hz were important factors in the cause of low back pain. Kelsey et al (1984) showed that the risk of low back problems increased systematically with the age of the vehicle concluding that this was likely to be due to deterioration of the vehicle's shock absorbers. Although not investigated it may also be that the older cars had worn out seats or poor seat design.

2.3.3 Muscular Effort

The task of driving always involves muscular effort; steering, braking, clutch work, using the hand brake, reversing etc. All these activities load the spine to varying degrees. For example, psoas major, a powerful hip flexor originating in the spine is used each time a foot is lifted onto a pedal. According to Troup (1978) accelerating, braking, cornering and other such movements move the body in relation to the seat and muscle reaction is required to stabilise the body. Adverse postures involving extreme positions of body parts also occur in driving. For example, reversing involves the extensors and rotators of the cervical and thoracic spine compressing the vertebral bodies and discs increasing spinal stress. There is yet, however, no evidence in the literature to suggest that the muscle effort of driving by itself leads to musculoskeletal pain. The link between low back pain and getting in and out of the vehicle (Damkot et al, 1984) for example, was more likely to be due to the postural stress caused by the flexion and rotation of the spinal muscles in an already painful back, where the flexed spine combined with constant activity of the complex musculature stretches the tissues from which symptoms arise aggravating the pain (Troup 1978). Troup (1978) also hypothesised that postural stress caused a stiffening and shortening of the spine which lead to a disturbance in the movement patterns and neuromuscular control of the spine. It could be, that the difficulty often experienced in straightening up to get out of a car after several hours driving, is an example of such mechanical and neuromuscular changes.

2.3.4 Fixed Posture

The demands of the driving task also force the maintenance of the same body position for long periods of time. Isometric muscle work is involved to a varying degree in the lower limbs (accelerator and clutch pedal operation), the upper limbs (steering wheel grip and control) and to hold the trunk, head and neck erect and stable. It is characterised by a prolonged state of contraction which usually implies a constrained posture (Grandjean, 1987). This contraction of muscle tissue leads to compression of the blood vessels thereby reducing the muscles' blood supply and disrupting nutrient delivery (sugar and phosphorous compounds) and metabolite removal, the most important of which are lactic acid and carbon dioxide. It is the accumulation of these metabolites that produces acute pain and localised muscle fatigue resulting in reduced power, impaired co-ordination and the increased risk of error. Delaying or preventing these undesirable effects could be achieved by periodically relieving the muscles of their activity, i.e. postural variance, for which there is little opportunity during driving. In fact during dynamic work the contraction of the muscle tissue itself ensures a good supply of oxygen and nutrients, and metabolite removal, such that dynamic effort with pacing can be carried on for some time without fatigue. Akerblom (1948), cited in Keegan (1953), believed that the ability to change position whilst sitting was the most important requirement of a comfortable seat. Also, Rebiffe (1980) hypothesised that features such as an automatic gearbox or power steering were more important for the freedom they gave the driver to change his posture, than to decrease muscle activity.

A change of posture (leading to a change in disc pressure) is also beneficial for the nutrition of intervertebral discs which have no blood supply of their own (Kramer, 1973). He demonstrated that compression of the disc causes diffusion of tissue fluid from the disc and that with reduction of pressure the tissue fluid diffuses back in bringing essential nutrients with it. Frequent changes of posture are therefore also necessary for the health and condition of the discs.

2.3.5 Postural Angles for Comfort

Troup (1978) advocated that the design of the car seat itself was the single most important item in the prevention of back discomfort in drivers. Secondary to this the driver should have good visibility (of traffic and displays) and be able to reach the pedals, steering wheel and other controls in postures and with movement directions that are biomechanically efficient and that do not cause musculoskeletal stress, particularly to the spine. Examples of undesirable driving positions are; a high or very small steering wheel placing demands on the shoulder muscles; and limited legroom causing increased hip flexion, and pelvic tilt which flattens the lumbar lordosis. Postural angles for driving comfort satisfying the above have been recommended (Table 1).

Table 1. Postural angles for comfort.

	Rebiffe (1969) degrees	Grandjean (1980) degrees
Neck inclination	20-30	20-25
Trunk-thigh angle	95-120	100-120
Knee angle	95-135	110-130
Foot-calf angle	90-110	90-110
Arms (to the vertical)	10-45	20-40
Elbow angle	80-120	-
Wrist angle	170-190	-

Rebiffe (1969) carried out an analysis of the drivers task and theoretically explored the posture and position of the body which best met the requirements of the driving task, placing particular importance on the visual demands of the task. Using a biomechanical model of the body (from distances between joints and optimum joint angles) and simple geometric construction he was able to propose theoretical joint angles for comfort and correct posture. Unlike Troup (1978), his belief was that discomfort often arose from poor dimensional arrangement of the driving workstation rather than from the actual seat itself. Grandjean (1980) based his calculations on similar assumptions of the positions of the head, feet and hands. However it must be questioned if these optimum postural angles are as relevant today with cars increasingly being fitted with such features as power steering, servo assisted brakes, automatic gearboxes and cruise control as standard, all of which reduce demands on the musculoskeletal system.

Pheasant (1992a) considered that it was the demands of the driving task itself and the layout of the controls, rather than the car seat design (as suggested by Troup, 1978), which resulted in postural discomfort. He felt that despite adjustability in the seat, in practise due to visual demands the backrest angle was unlikely to be set more than 10 degrees from the vertical and that in stressful driving situations, for example heavy traffic, individuals hunched themselves forward over the steering wheel and therefore did not benefit from the backrest and lumbar support. With this in mind, it was clearly most unlikely that the optimum position of the spine with a trunk-thigh angle and knee angle of 135 degrees as advised by Keegan (1953) could be achieved when carrying out the driving task. It is in this position that the natural lumbar curve is maintained, where intervertebral disc pressure is low and back muscle activity balanced and minimal. Such a posture would also require more effort in the muscles of the neck, shoulders, arms and abdomen to carry out the driving task, unless car workstation design was radically changed, for example lower steering wheel and windscreen and greater legroom.

2.4 Car Seat Design Considerations

As already reported, Troup (1978) advocated that the design of the car seat itself was the single most important item in the prevention of back discomfort in drivers. According to Troup (1978) postural stress as discussed in Section 2.3 is largely avoidable with a correctly positioned and adjusted lumbar support; adjustable backrest angle, seat tilt and height; and measures to dampen the effects of shock and vibration. The literature regarding the backrest and lumbar support is now discussed.

2.4.1 Backrest and Lumbar support

The most important requirement of a good seat in order to protect the vulnerable lumbar discs is the placement of a support over the lower lumbar region (Keegan, 1953).

Andersson et al (1974) measured lumbar disc pressure and electromyography (EMG) activity of several back muscles using four healthy subjects sitting in a car seat. Both disc pressure and EMG were lower in the experimental condition where the seat-backrest angle was 120 degrees, the seat tilt 14 degrees from the horizontal and the lumbar support 50 mm forward of the seat. Based on the assumption that low disc pressure and EMG activity was favourable (no comfort assessments were taken), they suggested that the backrest and seat adjustability should aim at these values.

This prompted Porter and Norris (1987) to carry out a study to investigate the preferred position and depth of the lumbar support in four experimental conditions:-

1. standing upright.
2. sitting upright (seat-backrest angle 90 degrees with seat cushion horizontal).
3. reclined sitting (seat-backrest angle 120 degrees with seat cushion angle 15 degrees and lower legs vertical).

4. reclined sitting (seat-backrest angle 120 degrees with seat cushion angle 15 degrees and legs extended onto a raised floor as in a car).

Using an experimental chair to evaluate spinal profile, data were recorded for 20 subjects (10 males and 10 females). The results showed that for all three seating conditions the subjects preferred the lumbar support 20 mm forward of the seat, producing a spinal displacement of 27.3 mm with the legs extended (simulating the car driving posture). This spinal displacement was approximately half that when standing, but when a lumbar support producing a lordosis similar to that when standing was tried, it was considered unacceptable in terms of comfort. A range of 13-27 mm was then suggested for in / out adjustment of the lumbar support. This was in contrast to the previous study (Andersson et al, 1974) where a lumbar support 50 mm forward from the seat was recommended, although subjective opinion regarding this was not documented. Males and females had almost identical 1st and 5th lumbar vertebrae heights and the preferred lumbar support position was lower in both of the reclined seating conditions. This and the fact that females consistently preferred the lumbar support 10 mm lower than males, indicated a need for height adjustment. A lumbar support which is too high causes kyphosis of the lumbar spine, as does a lumbar support which is too low by pushing the individual forward in the seat and into a slumped posture. A range of 195-260 mm from the compressed seat cushion to the centre of the lumbar support was recommended for its adjustability.

Work by other authors also supported the need for an adjustable lumbar support, for example Branton (1984) made a study of 114 subjects in which variation was found in the lumbar curve height i.e. a mean of 172 mm (SD 125) for men and 196 mm (SD 106) for women when sitting upright on a table.

2.4.2 Seat Dimensions, Profiles and Hardness

Generally, specific car seat features such as shape, cushion length, tilt, height, contour and hardness will obviously have an effect on some of the points mentioned in Section 2.3. For example, a cushion which was too long would either put pressure on the back of the calf or the person would sit forward and not get the benefit of the backrest and lumbar support. If a seat was too high or too hard there would be pressure on the underside of the posterior thigh which would lead to discomfort, or if a seat was too low, pressure would be localised around the ischial tuberosity area and the trunk-thigh angle would be small.

Seated pressure distribution and its effects on the body will be discussed fully in Chapter 6.4.2 in Part II of this thesis.

2.5 Summary

Few studies were found on driving and low back pain (musculoskeletal troubles) but all the available evidence indicates that the relationship warrants further investigation (Section 2.2). There are also many reasons, from purely a mechanical viewpoint of stresses on the musculoskeletal system, why a high prevalence of back pain could be expected, for example prolonged sitting, fixed posture, loss of lumbar lordosis and vibration, any of which could individually lead to musculoskeletal troubles. Poor posture resulting from the design of the car seat itself or driving workstation could also contribute to postural stress, for example the absence of a lumbar support or no steering wheel adjustment. Variables such as gender, lifestyle, work tasks, mood and motivation may also affect the reports of symptoms of discomfort in the lumbar area. Further work was clearly needed in order understand these relationships more completely. The recording of potentially related information regarding other factors which have been linked to musculoskeletal trouble (notably low back trouble), for example sports activities, smoking and occupational tasks, is necessary in any future studies as these factors may be confounding to any such relationships. It is probable as suggested by Rey (1979), that symptoms arise from multiple relationships and influences.

There is also a need to quantify this information, for example sickness absence, prevalence etc., in order to inform employers of the risks to their drivers. The aim of this understanding should be that driving is made comfortable even for those with back pain, so that then the healthy spine is unlikely to be harmed (Troup, 1978).

Chapter 3 Methodological Issues

3.1 Introduction

In order to look for an association between exposure, in this case driving, and disease such as musculoskeletal troubles, it was necessary to collect epidemiological data. The literature was reviewed to help identify types of study design, techniques for improving the quality of the data to be collected and methods of collecting the data. This all led to the formulation of the research plan.

3.2 Types of Study Design

As previously mentioned, epidemiological studies seek to find an association between exposure, in this case driving (cause) and disease such as musculoskeletal troubles (effect). Exposure must occur before the disease and the investigator may be involved at any point in time. Figure 3 graphically represents the experimenter at times A, B, C or D. For example the investigator can measure exposure at time A, disease at time B, prevalence at time C and mortality at time D. There are a number of ways of designing such studies, usually dependant on the constraints of time and resources and these are summarised with respect to their suitability for this survey in Table 2.

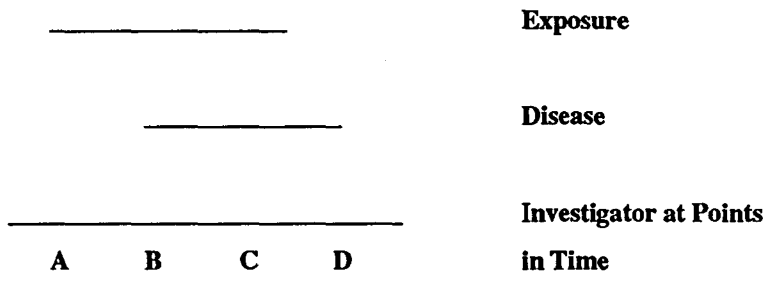


Figure 3. The basic relationships in epidemiology adapted from Monson, 1980.

Table 2. Study types in epidemiology.

Type and Reference	Description	Considerations
Experimental Study	Exposure to driving under control of the experimenter e.g. subjects drive 10 hours or 40 hours per week and are then monitored for musculoskeletal trouble.	Time required probably a minimum of 12 months. Difficult to control subjects free time therefore confounding possible. Ethical issues in possibly causing musculoskeletal trouble.
Descriptive Study	All information is available regarding driving exposure and musculoskeletal troubles. If information is available for each individual an analytical study can be carried out.	Access to personnel and medical records difficult to obtain. Does this specific information even exist? Databases and surveys such as The General Household Survey (1989) and The Labour Force Survey (1989) were unhelpful with regard to driving.
Cohort Study Walsh et al (1989)	a) Prospective Drivers and non drivers are observed over time until musculoskeletal trouble naturally occurs. b) Retrospective The trouble has occurred at the time of definition of driver and non driver groups.	a) Prospective Time required to develop the disease. Cost in terms of staff to monitor the study. Large study group generally needed. b) Retrospective Care needs to be taken to avoid selection bias.
Case Control Study Kelsey and Hardy (1975)	Individuals with disease (e.g. low back pain) compared to a suitably matched group without the disease, for driving exposure.	Access to a sample of low back pain sufferers which can be compared with non back pain sufferers without too much confounding. Time taken for organisation and liaison. Good for identification of risk factors.

Cross-Sectional Study Porter et al (1992) Damkot et al (1984) Burdoff and Zondervan (1990)	Information on exposure to driving and development of musculoskeletal trouble relate to the same point in time.	Quality of data, as the time between exposure and disease is not always known. Cannot be proved that any observed association is causal.
Longitudinal Study Pietri et al (1992)	In a given time period the number of new reports of musculoskeletal trouble is investigated in a group of drivers and non drivers. Can be prospective or retrospective.	Time taken to develop musculoskeletal trouble. Access to data.

As can be seen several strategies can be used in epidemiological study design and all are subject to some criticism. A prospective longitudinal / cohort study would provide a good understanding of the risk factors involved but such studies are rare because the time period involved for musculoskeletal troubles to develop could be great. The eventual choice of method is often dependant on the more practical constraints of time, cost, access to information, access to subjects, staff availability etc. Our constraints were cost and the fact that only 16 months of the project were available to design the study, carry out the interviews, analyse and present the results. If contacts with hospitals or companies, for example, had already been made it may have been possible to carry out a retrospective cohort / longitudinal study or a descriptive study, but it would also have take time to develop the necessary contacts and trust. With these constraints in mind the only possible options were to carry out either a cross-sectional study or to use an existing database. Although a cross-sectional study would not allow the examination of cause and effect, the prevalence data and other details collected may enhance the understanding of musculoskeletal troubles and driving.

3.3 Approaches in Epidemiology

In non-experimental epidemiological studies, such as a cross-sectional study design, certain procedures are required to ensure that the results have meaning. The following steps should be taken, according to Monson (1980) and Moser and Kalton (1992):-

1. Prevent selection bias by not using a knowledge of musculoskeletal troubles to define the study groups, i.e. avoid the selective admission of those with back pain into a driving group.

2. Minimise observation bias by showing objectivity when collecting information. For example, subjects must not know the specific reason for the survey in order that they do not assist the interviewer unknowingly, in obtaining a desired result.

3. Collect as much information as possible on confounding factors in order to be able to control for those factors if any associations are found. Confounding bias may occur when a third variable, for example increasing age, is associated with the exposure (i.e. driving) and independently could be the cause of the disease (i.e. musculoskeletal troubles). Monson (1980) said that: "Confounding bias does not result from any error of the investigator; it is a basic characteristic of existence".

The procedures of matching and stratification can be used to minimise the effect of confounding during the design of the study or data analysis. Matching guarantees comparability between groups for the factors matched, for example age, gender and smoking, but those factors cannot be evaluated in the study. Matching can either be in pairs (for example one non-driver aged 18-20, one driver aged 18-20) or frequency (the same percentage of 18-20 year olds in a sample of drivers and non-drivers). Due to practical difficulties and the potential loss of information, Monson (1980) felt that it was best to avoid matching in the data collection stage of a study, the data analysis stage being more suitable. The following criteria must be met for any matching carried out according to Monson (1980):-

1. There is no interest in evaluating the association between the disease and the factor to be matched. For example, if subjects are matched by sex, the relationship between sex and low back pain cannot be evaluated.

2. There is a reasonable likelihood that if matching is not done the factor would be confounding. For example, if increasing age is associated with increased low back discomfort.

3. There is a reasonable likelihood that the amount of confounding introduced is more than trivial. This involves being selective about which factors are most likely to be associated with risk.

4. There is no possibility that the factor is part of the causal pathway linking the exposure and disease. For example, if high daily mileage leads to low back discomfort which in turn leads to diagnosable low back pain, it is not

appropriate to match on low back discomfort when looking at the association. High mileage needs to be shown to be independently the cause of diagnosable low back pain.

5. Generally factors or variables to be matched on are not important sources of confounding.

The criteria above governing the technique of matching made it unsuitable for this study in exploring the association between driving and musculoskeletal troubles. For example, matching subjects by age meant that the effect of age could not be evaluated. Also, on a practical level it would take time to find enough subjects for the matched pairs.

Stratification is another means of increasing the precision of a random sample and is used in many sample designs. Prior to any selection of the sample, the population is divided into a number of strata for example age, gender or occupation and then a random sample is selected within each stratum. It can be carried out after simple random sampling as long as there are a sufficient number of cases for each stratum. Stratified random sampling tends to have greater precision than simple random sampling (Moser and Karlton, 1992) as it ensures that different strata in the population are represented in the sample and avoids selection bias. It is also more practical to carry out than 'matching'.

3.3.1 The Healthy Worker Effect

Occupational choice can be affected by health, age, sex, lifestyle and education, some occupations even being more attractive to sufferers of certain health problems, for example back pain sufferers avoiding heavy labour occupations. Inevitably though, some kind of selection process is involved and by definition occupational choice is one such self-selection process (Rey, 1979). The term 'the healthy worker effect' is an example of confounding bias and must be considered in the interpretation of any epidemiological data. It encompasses such situations as a previously acquired disease being wrongly attributed to a new job and that workers remaining in a particular job are all the healthy ones masking a potential problem.

According to Walsh et al (1989) cross-sectional surveys may underestimate the physical stress of certain work activities because subjects with severe low back pain for example may have been selected out of the more physically demanding jobs. Also the severity of the symptoms and the physical demands of the task i.e. the ability to continue normal activity are likely to affect the reporting of musculoskeletal troubles (Battie and Bigos, 1991).

3.4 The Research Plan

The literature revealed relatively few notable studies concerned with driving related discomfort and musculoskeletal problems. Examination of previously collected data, for example The General Household Survey (1989), was also generally unhelpful with regard to looking specifically at car drivers. Therefore, within the constraints of time and resources, despite the difficulties in interpretation, it seemed reasonable that a questionnaire based interview was the most effective way of collecting data for this exploratory cross-sectional study.

Initially several large companies with subsidiaries in Europe, for example Fisons and Boots plc, who it was anticipated would have large numbers of employees who drove cars as part of their job, were approached regarding conducting a survey. Replies to correspondence were slow and it seemed that large companies were reluctant to bring up the subject of musculoskeletal troubles with their employees. The whole Repetitive Strain Injury (RSI) explosion in Europe at the time and compensation cases in the media could have been the cause of this sensitivity. It would have taken time to develop the trust, interest and contacts necessary to conduct a survey.

An enthusiastic working arrangement was however developed with the Occupational Health Department of Sussex Constabulary. This department had access to a computer data base on the sickness absence of Sussex Constabulary. Also, Kelsey and Hardy (1975) as mentioned in Chapter 2.2, had identified police patrol drivers as being at particular risk. It was therefore concluded that the research should follow two avenues:-

1. A large survey of a random sample of the general public to look at the extent of the problem in the British population (n=600).

2. A survey of a sample of police officers from Sussex Constabulary (n=200).

The samples were as large as possible for reliability of the data, given the time available. The development of the questionnaire for the structured interviews, data collection and the results of the surveys are described in the next three chapters, followed by the overall discussion and summary.

Chapter 4 Development of the Musculoskeletal Troubles Questionnaire

4.1 Introduction

It was necessary to design a questionnaire which could be used as a structured interview to explore the following in the two surveys:-

1. Is exposure to driving related to an increased prevalence of sickness absence due to musculoskeletal troubles?
2. What effect does exposure to other factors, for example heavy lifting, age, gender, sports participation etc., have on this?
3. Does the type of vehicle driven or the amount of adjustability in the driver workstation have any effect on this relationship?

4.2 Design of the Questionnaire

It was decided to base the survey on the standardised format of the Nordic Musculoskeletal Questionnaire (NMQ) which was developed by a project group consisting of members of the Scandinavian countries and the USA at the request of the Nordic Council of Ministers (Kuorinka et al, 1987). The NMQ consists of a general questionnaire for the analysis of the prevalence of musculoskeletal trouble in different anatomical regions (Appendix 1, page 2) and optional questionnaires for more detailed analysis, including sickness absence due to neck, shoulder and low back trouble (Appendix 1, pages 3-5). A front page asks for subject details such as sex, age, weight, height and hand dominance. Period prevalence (12 months), point prevalence (7 days) and the intensity of the musculoskeletal trouble are reflected in the general questionnaire as follows:-

"Have you at any time during the **last 12 months** had **trouble (such as ache, pain, discomfort, numbness)** in:......" is intended to reflect period prevalence, in this case the specified period being 12 months.

"Have you had trouble in the **last 7 days**:....." is intended to reflect point prevalence.

"During the **last 12 months** have you been **prevented** from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble:...." is intended to reflect the intensity or severity of this trouble.

The more detailed question sheets were intended to concentrate more thoroughly on the common sites of musculoskeletal troubles i.e. neck, shoulders and low back, and the severity of the impact of the trouble on work and leisure activities. Diagnostic labelling was avoided by using the term 'trouble' to mean 'ache, pain, discomfort or numbness' experienced in different body areas. The questionnaire was not intended to be used for the diagnosis of musculoskeletal disorders and it is accepted that a medical examination would be required for this. It seems however that firm diagnosis of low back pain is difficult anyway: Dillane (1966) found that over a four year period in general practice that there was no evident pathological cause of acute back pain in 83.7% of 345 cases: Bigos et al (1986) reviewing the literature estimated that only 12-15% of back problems have obvious physical findings indicating the exact cause of the symptoms. Similarly a disc protrusion found on a CT scan may be asymptomatic in the patient and may be just part of the normal ageing process (Conte and Banerjee, 1993).

The advantages of using this questionnaire are now considered:-

1. The NMQ was designed to answer a similar objective as that required by the project: "Do musculoskeletal troubles occur in a given population and if so which body parts are affected?" This saved time and cost in terms of constructing and piloting a new questionnaire.

2. It was suitable for cross-sectional studies and could either be used as a self-administered questionnaire or as a structured interview. Additional questions could be added relevant to the actual study, for example occupation and driving.

3. It had been tested for reliability and validity with several occupational groups in Scandinavia (Kuorinka et al, 1987) and by the Health and Safety Executive (HSE) in England (Dickinson et al, 1992) whereby subjects completed and refilled the questionnaire and their responses were compared to their clinical history. The results were judged to be satisfactory. The recommendations made by the HSE with regard to its use with the British population were taken into account in the final layout, wording and administration. For example the definition of the word 'trouble' to mean 'ache, pain or discomfort' was expanded to mean 'ache, pain, discomfort or numbness'.

4. The NMQ has been extensively used in Scandinavia (e.g. Jonsson and Ydreborg, 1985) for more than ten years and by the HSE for the last five years to compare different occupational groups. Unfortunately the work is mainly unpublished due to its confidential nature or it has not been translated into English. Personal communication with Dickinson (1993) at the HSE and Ydreborg (1993) in Sweden supported the view that the questionnaire was suitable for the driver study. It has also been used in some recent published studies, for example Andersson et al (1987) studied Swedish bus drivers and shunters, Burdoff and Zondervan (1990) studied low back pain in crane-operators, and some of the questions from the NMQ were used in the study by Biering-Sorensen and Hilden (1984) of low back trouble in the general population.

5. The NMQ is short, can accommodate different work forces and individuals and has been shown to be non-threatening and accepted by subjects.

6. The data collected were potentially comparable with that from other similar studies due to standardisation of the questions. Dickinson et al (1992) however did advise some caution with this, where the method of administration and response rates were not known, as these were shown by her work to be of importance. In supermarkets where HSE staff administered the questionnaire, all questionnaires were returned. If the questionnaires were issued by the retail staff the response rate fell to between 85-95%. The response rate fell further (45-70%) where subjects returned their own questionnaires and with this group the prevalence of neck trouble was higher suggesting that the replies were mainly from individuals who had a self-interest in returning the questionnaire.

Bering-Sorensen and Hilden (1984) also advised that the circumstances of data collection may influence the results significantly.

7. In a recent study carried out by Ohlsson et al (1994), the NMQ was found to be fairly good at indicating the extent of neck / upper extremity musculoskeletal troubles when compared with a detailed clinical examination of these body areas (80% sensitivity for the shoulders and 42-65% sensitivity for the neck, elbows and hands). The subject group was 165 females employed in either repetitive industrial work or varied work. However, they also concluded that a clear view of the size of the problem would only be obtained by a full clinical examination, as the questionnaire tended to give an underestimation. Another recent study by Deakin et al (1994) of two similar workstations in a manufacturing plant showed the NMQ to be sensitive enough to pick up differences in the pattern of injuries between the two workstations. Finally, a paper by Bru et al (1994) supports the need for a means of assessment of musculoskeletal pain sensitive enough to distinguish between the upper back, neck, shoulders, low back and extremities, for example the NMQ.

N.B. These studies were published after the interviewing for this thesis had been completed. They are also referred to in Chapter 7.2.2.

There are well documented considerations in the use of any questionnaire (Moser and Kalton, 1992; Brigham, 1975; Sinclair, 1975). Further to awareness of these considerations, the NMQ requires a response rate exceeding 80% (Dickinson et al, 1992) in order to avoid returns predominately from those with troubles. In a personal communication Dickinson (1993), also advised a sample size minimum of 50 in order that adequate numbers for analysis were represented in each group. Males and females should also be analysed separately as females tended to report a higher frequency of troubles than men and in different parts of the body. For example, in comparable occupations females had a higher prevalence of neck and shoulder trouble and males had a higher prevalence of low back trouble (Jonsson and Ydreborg, 1985). No explanations were suggested for these differences.

Blind trust in data based on subjective statements should be discouraged and Biering-Sorensen and Hilden (1984) suggested using check questions. Such questions are included in the NMQ. For example, the subjects are asked if they had experienced neck trouble in the 'last 12 months'; they are then asked at a later stage if they had 'ever' had neck trouble; the latter acting as a check question. The results may also be affected by poor memory and the fact that recent and more serious musculoskeletal troubles would be remembered and older and less serious troubles could be forgotten. Long term memory appears to be related to the duration of a painful experience and the frequency of reoccurrence (Wyke, 1980). Interviewing subjects could avoid the ambiguities of both of these problems to a certain degree. Finally questionnaires which focus on interest in the musculoskeletal system may result in a higher frequency of reported troubles (Andersson et al, 1987).

4.2.1 Additional Questions

A factor that is confounding may only account for a fraction of the association between exposure and disease. Therefore, when deciding which additional questions to add to the NMQ, a balance needs to be kept about what is possible in the specific interview situation and what information it is important to obtain because of its possible influence on musculoskeletal troubles. An example of such is age, however, even with the factor of age there is no certainty. Reisbord and Greenland (1985) concluded that the effect of age alone in predicting the prevalence of low back pain was not striking, and that it was only its interaction with other variables, notably marriage status, that gave it importance. They found a high prevalence of low back pain in subjects who were no longer married and over 35, hypothesising that this could be due to the increased emotional stress and home responsibilities. Burton et al (1989) also judged the effect of age alone on low back trouble to be slight, but that its correlation with other related variables, for example sports activity and back flexibility, was important. Waddell (1987), reviewing the work of other authors, also suggested that low back pain does not progressively increase with age, nor correspond with age-related disc degeneration, but problems with low back pain in terms of sickness absence, peak at about 40 years of age. The reason for this is unknown.

Gender too was considered important in predicting low back pain in the regression model produced by Reisbord and Greenland (1985) along with age, marital status and education. In the study by Burton et al (1989), some variables produced by discriminant analysis, important in low back trouble were the same for both sexes (age, sports activity), but there were gender differences in their relative importance. Also, there were some specific sex differences in other variables. For example, 'having a heavy job' was only predictive in females. Although data regarding height and weight were collected as part of the NMQ, no studies were found indicating a clear association between these variables and low back pain.

In the previously mentioned study by Frymoyer et al (1983), current sports participation was similar for subjects whether they had no low back pain, moderate low back pain or severe low back pain. Although there was a trend (not significant), for subjects with moderate pain to have a higher level of sports activity than the other two groups. Kelsey et al (1984) also found that sports participation did not affect the risk of a prolapsed lumbar vertebrae. However Burton et al (1989) found that participation in sports at school reduced the risk of low back trouble but in contrast adult sports participation increased the risk. They concluded that early physical fitness enhanced back mobility and health, whereas sports related injury in adult life reduced back mobility increasing the risk of low back trouble. It was decided that it was necessary to investigate current sports participation as a possible factor in contributing to low back trouble. A list of sports felt to be 'high risk' for neck and back ailments was taken from a study by Porter and Porter (1990) of the views of physiotherapists, osteopaths and chiropractors. This list was ranked in order of risk and subjects were asked for how many hours each week they regularly participated in each of these sports (Appendix 1, page 6).

Many authors (Waddell, 1987; Biering-Sorensen et al, 1989; Frymoyer and Cats-Baril, 1991) have reported an association between cigarette smoking and back pain and Kelsey et al (1984) found a higher risk of prolapsed lumbar intervertebral disc in cigarette smokers. Following analysis not explained in the paper, she hypothesised that the risk for prolapsed disc was increased by 20% for each ten cigarettes per day smoked during the last year. Frymoyer et al (1983) were surprised that in their study only 39.6% of their asymptomatic men were cigarette smokers compared with 53% of men with severe low back pain. Possible theories regarding this association have been summarised from the literature in Battie and Bigos (1991) and include smokers being at risk from the following; decreased bone mineral content and osteoporosis; coughing and increased intervertebral disc pressures and changes in vertebral body blood flow affecting disc metabolism. Another view discussed by Battie et al (1991), is that certain lifestyle factors are more common amongst smokers so that is not the smoking itself that increases the risk of low back trouble. In the light of these studies a question was included regarding cigarette smoking.

Hildebrandt (1987) comprehensively examined the potential risk factors for low back pain. He analysed three recently published books and two review articles by experts eminent in the field of low back pain and identified 73 individual factors and 25 work related factors, demonstrating the difficulties in interpretation of the literature. The references given by the sources were also analysed. By using the total number of times a factor was mentioned in the literature as an indication of its importance and so how likely it was to be confounding, he found the following (Table 3) to be the most important, having been mentioned in at least three of five epidemiological sources:

Table 3. Risk factors for low back pain mentioned in three of five literature sources (Hildebrandt, 1987).

Personal	Work Related
age	heavy manual handling
back complaints in the past	heavy physical work
physical fitness	heavy or frequent lifting
psychosocial problems	prolonged sitting postures
relative muscle strength	pulling / pushing
work experience	trunk rotation
	vibrations

Where possible, within the limitations of the questionnaire, questions were included regarding each of these factors (Appendix 1, pages 6-8). Kelsey and Golden (1988) also summarised the factors that affect the frequency of low back pain as being occupational tasks, physical fitness, cigarette smoking, static postures, vibration and driving. The list of occupational task demands in the questionnaire was taken from Pheasant (1992b). The author is however aware that it is difficult to obtain quality data about many of these factors without the back up of objective measures. For example, the work of Baty et al (1986) concluded that it was not possible to have full confidence in the results of studies where the absolute values of the risk factors were determined from a questionnaire only. Stubbs et al (1983a) also acknowledged that in the aetiology of back pain there was often reliance on subjective measures, for which there was often little opportunity for validation. It was not possible in the time available to carry out the surveys of the general public and the police, to validate such questions, by comparisons with an objective analysis of the tasks at work.

Scales for measuring factors like job satisfaction and motivation (Warr et al, 1979) and anxiety / depression (Zigmond and Snaith, 1983) were considered, but were felt too lengthy and threatening for a public interview. The police too would be suspicious of such a scale in the light of the many changes occurring at the moment, for example those connected with the Sheehy Report with regard to performance related pay, fixed term contracts and abolishment of the housing allowance (Bilmes, 1993). Although some studies indicated the importance of work perceptions and psychosocial factors (Waddell, 1987; Battie and Bigos, 1991), it was decided that such questions would test the patience and co-operation of interview subjects. It was therefore decided to include a single question about job satisfaction with a five point scale in the final version as a crude indicator.

A series of questions regarding the age, type, and the adjustment features of the main vehicle driven were added (Appendix 1, pages 9-15). Although space was available to list two vehicles regularly driven, it was intended to ask subjects if possible, to indicate the main vehicle driven. Questions covering the distance travelled each week and over the last 12 months, the distance to work and time taken were also included to give an indication of exposure to driving. These questions were all placed at the end of the questionnaire to avoid the subject linking driving with musculoskeletal troubles directly.

4.2.2 Piloting the Questionnaire

The complete questionnaire was shown to four experts in qualitative techniques for their consideration. Comments were noted regarding layout, wording and suitability for example and amendments were made as necessary. A sample of 25 members of the general public were then interviewed to perfect the interview dialogue and to check for errors and inconsistencies. These data were not included in the main survey as the interview dialogue and wording changed as a result of the pilot study. The questionnaire did show itself to be suitable for use as a structured interview with completion times ranging from 5-25 minutes dependant on the number of musculoskeletal troubles. The average completion time was between 10-15 minutes.

The data obtained in the two surveys reported in Chapters 5 and 6 were checked and coded prior to entry on computer by data preparation staff at the university. Coding frames were developed for the 'open ended' questions. Statistical analysis was carried out using SPSS (Norusis, 1990).

Chapter 5 The General Public Survey

5.1 Aims

The aim of this survey was to obtain a sample of non-drivers, low mileage drivers, high mileage drivers and people who drove as part of their job, in order to investigate any differences in the prevalence and sickness absence data according to their exposure to driving.

5.2 Procedure

For the survey of the general public a team of six interviewers (four females, two males) were carefully trained in the reasons behind the study, the use of the questionnaire, the interview dialogue, good interview technique and avoiding interviewer bias. They were then given the opportunity to practise in the field and to voice any concerns. It was essential to standardise administration of the questionnaire in order to enable adequate conclusions to be drawn (Andersson et al, 1987).

Over a ten day period in August 1993, 600 members of the general public were randomly selected to be interviewed roughly within the strata of age and gender. Special cases, for example, wheelchair users, were not interviewed as their vehicles may have adaptations and their physical disabilities may include musculoskeletal troubles. Selection bias was avoided because factors such as exposure to driving and history of musculoskeletal problems were not known beforehand by the interviewers. This and the fact that questions regarding driving were at the end of the interview also avoided the problem of subjects selecting themselves because of self interest. Venues chosen for the interviewing included town centres, shopping malls, sports halls, motorway service areas, holiday resorts, parks and small companies. Permission was granted in advance by the relevant bodies, for example county councils, local police and managers in order to carry out the interviews.

5.3 Data Analysis

All of the analyses were performed using SPSS for Mackintosh computers (Norusis, 1990). The data could have been manipulated and explored in many ways but it was decided to use the following statistical methods in addition to basic descriptive statistics.

Chi-square

This statistic was used to compare the observed frequency of cases in each cell with the expected number for that cell (for example point prevalence of neck trouble) when there were two or more unrelated samples (for example males and females). It was used for all the non-parametric dichotomous data comparisons.

Kruskal-Wallis 1-way ANOVA

This statistic was used to test for significant differences between three or more groups such as the three car categories (supermini, small family car, large family car) when a rating scale was used. For example, the question:-

"What is the **total length of time** low back trouble was suffered in the **last 12 months**?"

The choices of answers were a rank scale of the number of days (0 days, 1-7 days, 8-30 days etc.). Individual cases were ranked and the differences between the mean ranks for the selected groups were examined.

Spearman's Rank Correlation Coefficient

This gives a measure of association between two variables which are at least on an ordinal scale (as above). On the advice of a statistician it was also used for correlations with the prevalence data.

Pearson's r Correlation

This statistic gives a measure of linear association, assessing the extent to which high scores on one variable were related to high scores on another variable. It also assesses the strength, direction and probability of the association. The data must be interval or ratio level, for example days ever absent, number of miles driven and number of hours driven.

Students t-test

This statistic was used on the interval data, for example days ever absent with low back trouble, to determine whether the means of two independent samples, for example males and females, differ. It compares the differences between the means of the two samples with the probability of those two means differing by chance.

1-way ANOVA

This statistic was used to compare the means of two or more independent samples, for example the categories describing the mean number of days ever absent with low back trouble, in the three 'car types' (supermini, small family car, large family car). It compares an estimate of the variance between groups to an estimate of the variance within groups.

Prevalence Odds Ratio

The odds ratio is the odds of being a case to not being a case for those with the risk factor (for example driving more than 20 hours at work) to these same odds for without the risk factor (Kahn, 1983). In cross-sectional studies the prevalence odds ratio is essentially equal to the prevalence ratio for rare diseases or diseases with low prevalence, but this is not the case with low back trouble. Readers should refer to Kleinbaum et al (1982) or Hirsch and Riegelman (1984) for a description and further discussion of the technique. The statistic was used to examine the prevalence data for low back trouble and exposure to driving.

Multiple Regression Analysis

Multiple regression analysis was used to explore the variables important in contributing to sickness absence due to low back trouble. Readers should refer to Glantz and Slinker (1990) for further detail regarding the technique and the terminology used in the text.

5.4 Results

The musculoskeletal troubles data were explored as explained in Section 5.3. Relevant descriptive data, statistically significant findings and consistent trends only are reported.

5.4.1 Personal Details

Age and gender

The age distribution of the whole sample is described by gender in Table 4. The sickness absence and prevalence data for the whole sample are shown by gender in Appendix 2.

Table 4. The age distribution of the whole sample (n=600) by gender.

Gender	Mean (SD)	Age Range
Whole sample (n=600)	38.48 (13.36)	17-74
Males (n=303)	38.48 (13.09)	17-73
Females (n=297)	38.47 (13.65)	17-74

No statistically significant differences were found between the sexes for any of the low back sickness absence criteria. However, the total length of time which neck and shoulder trouble were experienced in the last 12 months were both significantly higher for females (Figures 4 and 5). The point prevalence (7 days), period prevalence (12 months), and severity of neck, shoulder, upper back and wrist hand trouble were also significantly higher in females (Figure 6). Refer to Chapter 4.2 for an explanation of the terms. Males and females were often considered separately in the analysis.

The sample showed no significant correlations with age for any of the sickness absence criteria. Also no significant differences were found between the six age groups (17-24, 25-34, 35-44, 45-54, 55-64, 65-74 years) for any of the low back sickness absence criteria or for low back trouble experienced.

Figure 4. Number of days neck trouble experienced in the last 12 months according to gender (n=600).

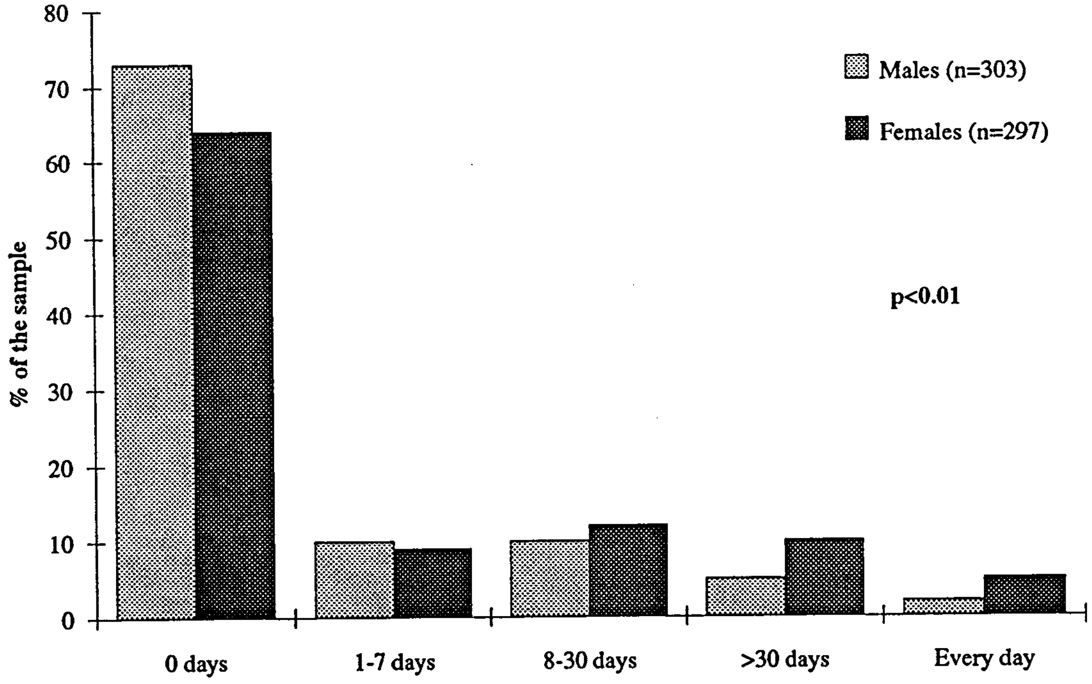


Figure 5. Number of days shoulder trouble experienced in the last 12 months according to gender (n=600).

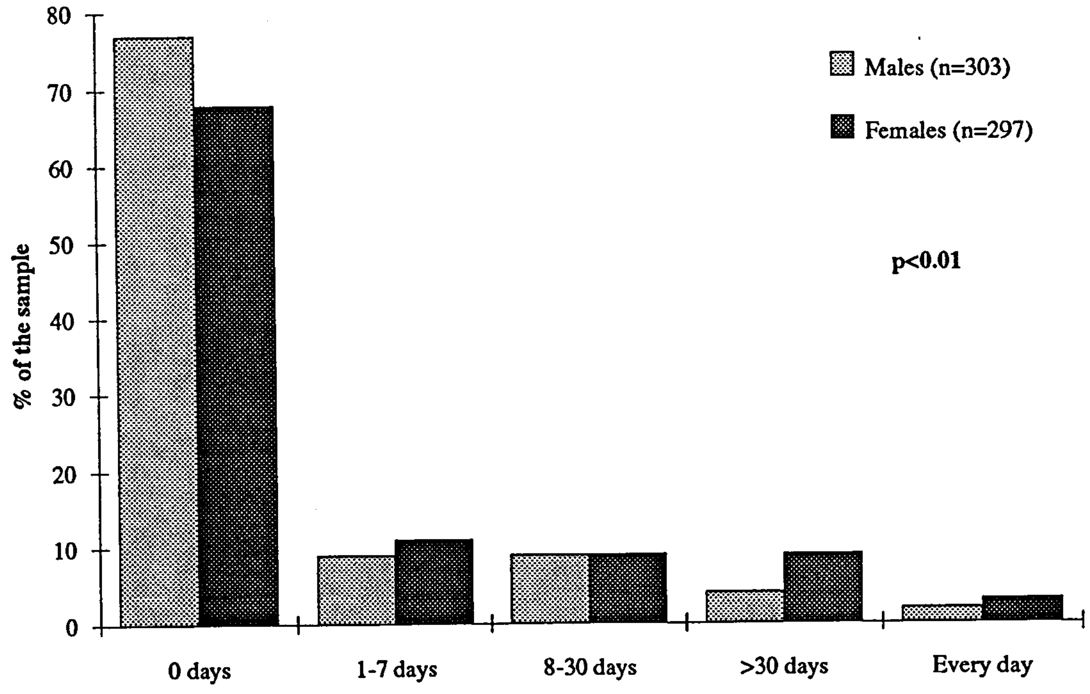
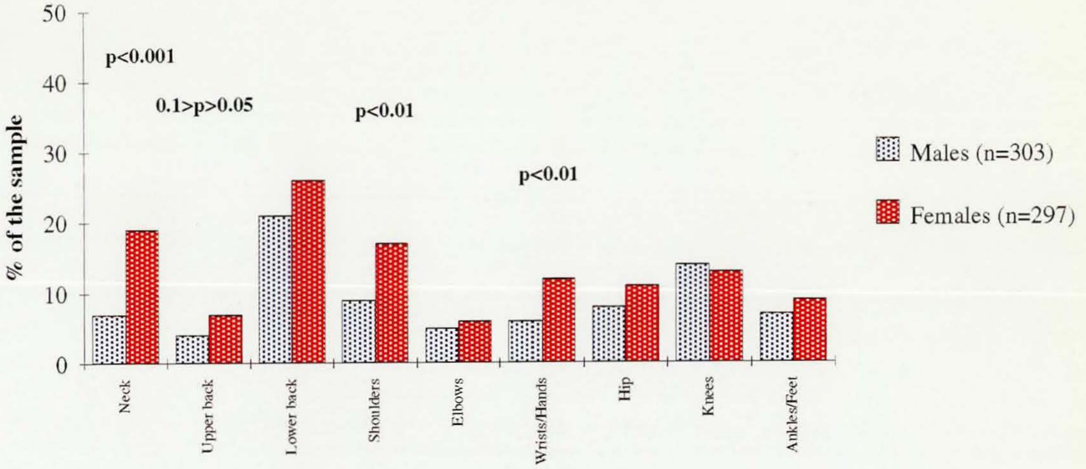
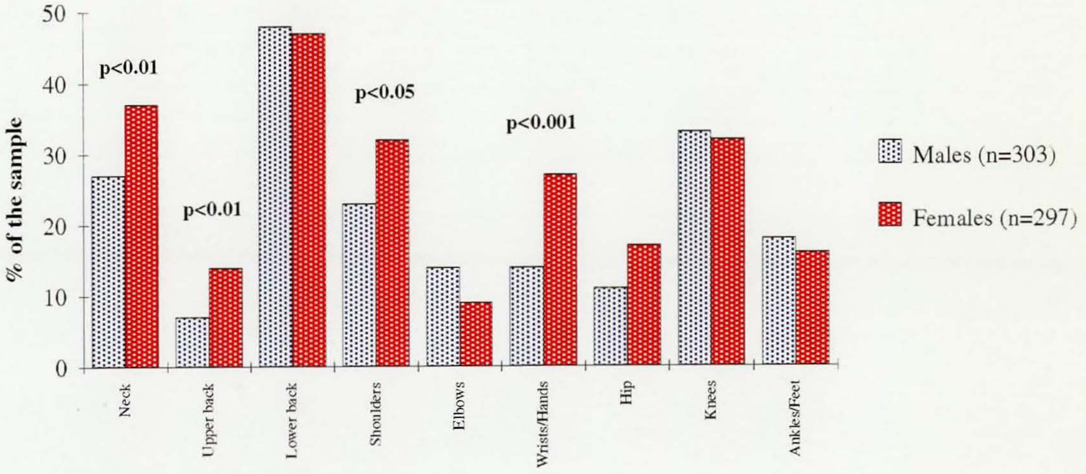
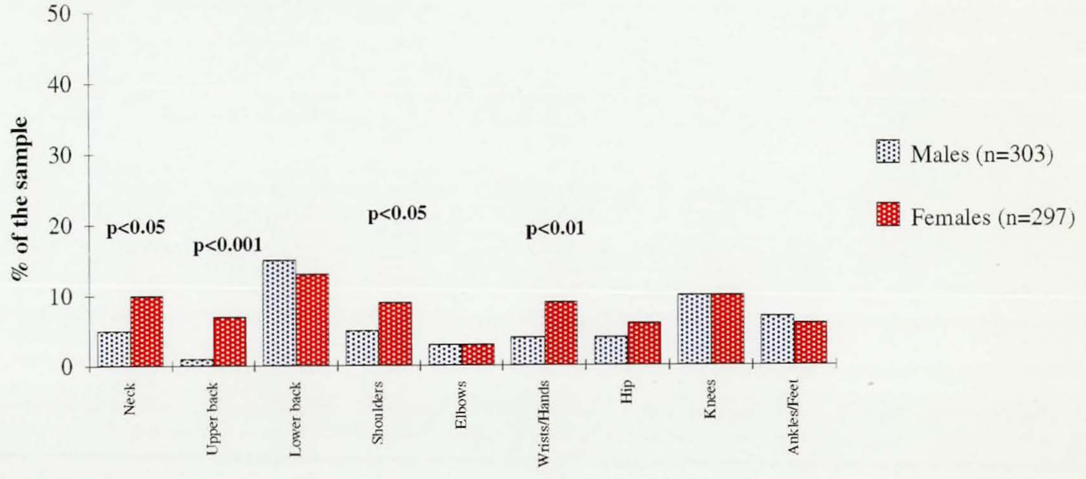


Figure 6. The prevalence of musculoskeletal troubles in the general public (n=600).


Point prevalence (i.e. last 7 days)


Period prevalence (i.e. last 12 months)


Severity (i.e. preventing normal activity)

Significant differences between the age groups were however found for the following, the clear pattern being increased trouble with increasing age: ankle point prevalence (0.1>p>0.05), ankle period prevalence (p<0.05), elbow point prevalence (p<0.001), elbow period prevalence (p<0.001), hip point prevalence (p<0.05), severity of hip trouble (p<0.05), neck lifetime prevalence (0.0>p>0.05), shoulder lifetime prevalence (0.1>p>0.05), the number of occasions ever absent from work with neck trouble (p<0.05) and the number of days ever absent from work with neck trouble (0.1>p>0.05).

Body Mass Index

Height and weight were examined separately and no clear picture emerged. Given that both variables were self reported, a crude measure of body mass index was calculated by dividing weight (in kilograms) by the square of height (in metres). It could provide an indication of whether an individual was overweight and so at possible at risk from musculoskeletal problems. The results for the whole sample are shown in Table 5.

Table 5. Body mass index according to gender.

Gender	Body Mass Index Mean (SD), Range	Breakdown
Males (n=303)	24.6 (3.7), 17.2-50.5	6% underweight (under 20) 62% acceptable (20-25) 27% overweight (26-30) 4% seriously overweight (31-40) 0.3% dangerously overweight (over 41)
Females (n=297)	23.6 (8.7), 14.3-58.7	6% underweight (under 19) 70% acceptable (19-24) 16% overweight (25-29) 7% seriously overweight (30-40) 1% dangerously overweight (over 41)

Significant positive correlations were found between the number of occasions and the number of days ever absent from work with low back trouble and body mass index, but for the sample of males only (Table 6).

Table 6. Correlation coefficients (Pearson's r) and significance for body mass index and sickness absence criteria.

Criteria	Males (n=303)	Females (n=297)
The number of occasions ever absent from work with low back trouble.	.1445 *	.0142
Total number of days ever absent from work with low back trouble.	.1490 **	-.0008

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

The point prevalence, period prevalence and severity of knee trouble positively correlated with body mass index, again for the sample of males only (Table 7). The point prevalence and period prevalence of elbow trouble also showed significant positive correlations just for the males (Table 7).

Table 7. Correlation coefficients (Spearman's rank) and their significance for body mass and the prevalence and severity of knee and elbow trouble.

Knee trouble	Males (n=303)	Females (n=297)
Point prevalence (7 days).	.1247 *	.0017
Period prevalence (12 months).	.1432 *	-.0111
Severity over the last 12 months.	.1546 **	-.0038

Elbow trouble	Males (n=303)	Females (n=297)
Point prevalence (7 days).	.1156 *	.0462
Period prevalence (12 months).	.1194 **	.0423
Severity over the last 12 months.	-.0775	.0209

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

5.4.2 Lifestyle

Smoking

The sample consisted of 145 smokers (24 %) and 59% of these smokers were male and 41% female. The number of cigarettes smoked a day by gender is shown in Table 8.

Table 8. The number of cigarettes smoked a day by gender.

Gender	Number of cigarettes per day Mean (SD), Range
Whole sample (n=145)	14.47 (8.17), 1-40
Males (n=86)	14.08 (7.82), 1-40
Females (n=59)	15.03 (8.69), 1-40

No significant correlations were found between cigarette smoking and low back, neck or shoulder trouble. Comparing smokers with non-smokers; smokers were absent from work with neck trouble ever, on more occasions ($p<0.05$) and for a greater number of days ($0.1>p>0.05$), than the none smoking group (Table 9). These differences were not apparent when males and females were considered separately.

Table 9. Means, standard deviations and the significance levels for sickness absence variables for smokers and non-smokers.

Criteria	Smokers (n=145) Mean (SD)	Non Smokers (n=455) Mean (SD)	Significance of F
The number of occasions ever absent from work with **neck trouble.**	0.21 (.56)	0.10 (.41)	*
Total number of days ever absent from work with **neck trouble.**	4.09 (18.12)	1.41 (9.46)	(a)

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Sport

The number of hours which ten 'risk sports' (i.e. high risk for neck and back injuries, Porter and Porter, 1990) were participated in regularly each week are shown in Table 10. It can be seen that there was a highly significant difference ($p<0.001$) between the number of hours of participation in these sports for males and females. Each sport was not represented in large enough numbers to allow separate analysis.

There were significant positive correlations between the number of hours that the top 10 'risk sports' (i.e. high risk sporting activities for neck and back ailments) were participated in and the number of days ever absent from work with low back trouble and the length of time that neck and shoulder trouble had prevented normal activity (Table 11). It can be seen that there were gender differences in these correlations.

Table 10. The number of hours 'risk sports' were participated in each week by gender.

Gender	**Hours of 'risk sports'** Mean (SD), Range
Whole sample (n=600)	1.12 (2.22), 0-16
Males (n=303)	1.46 (2.63), 0-16
Females (n=297)	0.76 (1.62), 0-10

p<0.001 between males and females (students t-test)

Table 11. Correlation coefficients (Pearson's r) for 'risk sports' (number of hours) and sickness absence criteria.

Criteria	**Whole sample** (n=600)	**Males** (n=303)	**Females** (n=297)
Total number of days ever absent from work with **low back trouble.**	.1070 **	.0832	.1557 **
Total length of time **neck trouble** has prevented normal activity in the last 12 months.	.0760 (a)	.1306 *	.0517
Total length of time **shoulder trouble** has prevented normal activity in the last 12 months.	.0849 *	.1116 *	.0865

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

5.4.3 Work Details

Occupations

Of the whole sample 72% were currently employed, 56 % of whom were males and 44% were females. The range of their occupations (using OPCS divisions from the Labour Force Survey, 1989) were as follows:-

		Males (n=242)	**Females** (n=191)
1.	Professional and related supporting management; Senior National and Local Government Managers	12%	7%
2.	Professional and related in Education, Welfare and Health	12%	29%
3.	Literary, Artistic and Sports	3%	2%
4.	Professional and related in Science, Engineering, Technology and similar fields	16%	7%

5.	Managerial	12%	5%
6.	Clerical and related	2%	18%
7.	Selling	9.5%	9%
8.	Security and Protective Service	4%	0%
9.	Catering, Cleaning, Hairdressing and other Personal Service	6%	11%
10.	Farming, Fishing and related	0.5%	2%
11.	Materials Processing; Making and Repairing (excluding Metal and Electrical)	4%	3%
12.	Processing, Making, Repairing and related (Metal and Electrical)	4%	0%
13.	Painting, Repetitive Assembling, Product Inspecting, Packaging and related	2%	2%
14.	Construction, Mining and related not identified elsewhere	2%	0%
15.	Transport Operating, Materials Moving and Storing and related	10%	5%
16.	Miscellaneous	0.5%	0%
17.	Inadequately described and not stated	0.5%	0%

It can be seen that more females than males carried out clerical work (18% compared with 2%) and were involved in education, welfare and health (29% compared with 12%). No females in this sample had occupations which were classified as security and protective services; processing, making and repairing (metal and electrical); and construction and mining.

Hours worked

The mean number of hours worked was 41.02 (SD 16.77, range 2-120). Most of the sample were satisfied with their job as follows:-

	Males (n=242)	Females (n=191)
Satisfied	57%	58%
Partially satisfied	23%	21%
No feelings either way	4%	5%
Not satisfied	5%	4%
Would like a change	11%	12%

Travel to work

They travelled to work as follows:-

	Males (n=242)	Females (n=191)
Walk	8%	15%
Cycle	3%	4%
Public transport e.g. bus	12%	17%
Drive themselves by car	62%	52%
Other	15%	12%

5.4.4 Vehicle details

The range of main vehicles driven by the sample of 465 drivers of all vehicles were as follows:-

Supermini e.g., Ford Fiesta	27%
Small family car e.g. Fiat Tipo	33%
Large family car e.g. Vauxhall Cavalier	21%
Executive car e.g. BMW 520i	5%
Luxury car e.g. Mercedes-Benz 500SE	0.5%
Coupe/Sports car e.g. Porsche 968	3%
MPV e.g. Renault Espace RT	0.5%
Off-roader e.g. Land Rover Discovery	1%
Motorbike	0.5%
Van-Light Commercial	3%
Van-Heavy Commercial	0.5%
HGV	3%
Bus	2%
Other	0.5%

The years in which the cars only (n=422) were registered were as follows:-

1993	5%	1987	7%	1981	2%
1992	9%	1986	6%	1980	1%
1991	7%	1985	7%	1979	1%
1990	12%	1984	4%	1978	1%
1989	14%	1883	6%	1977	1%
1988	10%	1982	4%	1976 and older	3%

Vehicle Adjustments

Adjustable features on the 422 cars only in the sample were reported as follows:-

38% had seat height adjustment

39% had cushion tilt adjustment

91% had backrest angle adjustment

26% had lumbar support adjustment

27% had steering wheel adjustment

Cushion tilt does indirectly effect a change in seat height, therefore the percentage of subjects whose cars did not have either adjustment was calculated and found to be 73%. Of the sample of cars, 51% had a sunroof, 10% had an automatic gearbox and 6% had cruise control.

Considering the sample of car drivers, 7% reported that there was not enough headroom in their vehicle, 10% reported that their pedals were in an uncomfortable position and 5% reported that their steering wheel was in an uncomfortable position.

5.4.5 Exposure to Driving

There was a need to define more clearly the driving group in order to explore reported discomfort and sickness absence with car drivers. The numbers of drivers of other types of vehicle in the sample, for example truck drivers, were too small for separate analysis (Section 5.4.4). The results from this section onwards now refer mainly to the sample of car drivers, and for some of the analyses the sample also contains non-drivers. Some of the statistics of the sample with regard to exposure to driving are given in Appendix 4. It can be seen for example, that the sample of car drivers 'as part of their job' had 16.2 (SD 67.3) days ever absent with low back trouble compared with 4.96 (SD 16.73) days for 'social, domestic and pleasure' drivers and 1.66 (SD 4.7) days for non-drivers ($p<0.01$).

Discomfort

Considering the sample of car drivers (n=422), 54% reported some discomfort with their car and the frequency of this discomfort was reported as follows:-

Always	2%
Often	8%
Sometimes e.g. long journeys	30%
Rarely	14%
Never	46%

The body areas in which discomfort was reported are shown in Figure 7 and under what circumstances are shown in Figure 8.

Annual Mileage

The mileage over the last 12 months is shown by gender in Table 12 for the sample of car drivers and the subset of those who drove cars as part of their job. There were significant differences between males and females with males having the higher mileage. Table 13 shows annual mileage by age-group and gender with significant differences between the groups.

Table 12. Annual mileage by gender for all car drivers (n=422) and the subset of those who drove cars as part of their job (n=113) with significance levels.

	Males (miles) Mean (SD)	**Females (miles)** Mean (SD)	**Significance of** F
All car drivers Males (n=222) Females (n=200)	17,777 (16,871)	9,707 (10,796)	***
Car drivers as part of their job Males (n=79) Females (n=34)	28,084 (16,033)	22,284 (13,341)	*

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Figure 7. Body areas in which car drivers reported discomfort (n=422).

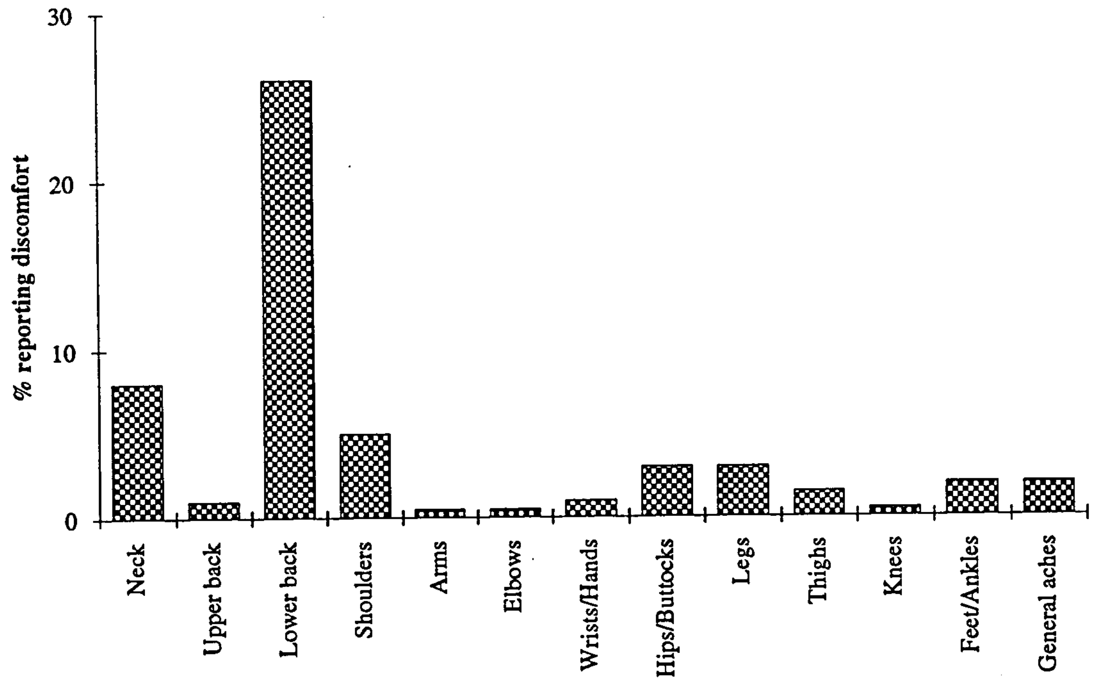


Figure 8. Circumstances under which discomfort occurs for car drivers (n=422).

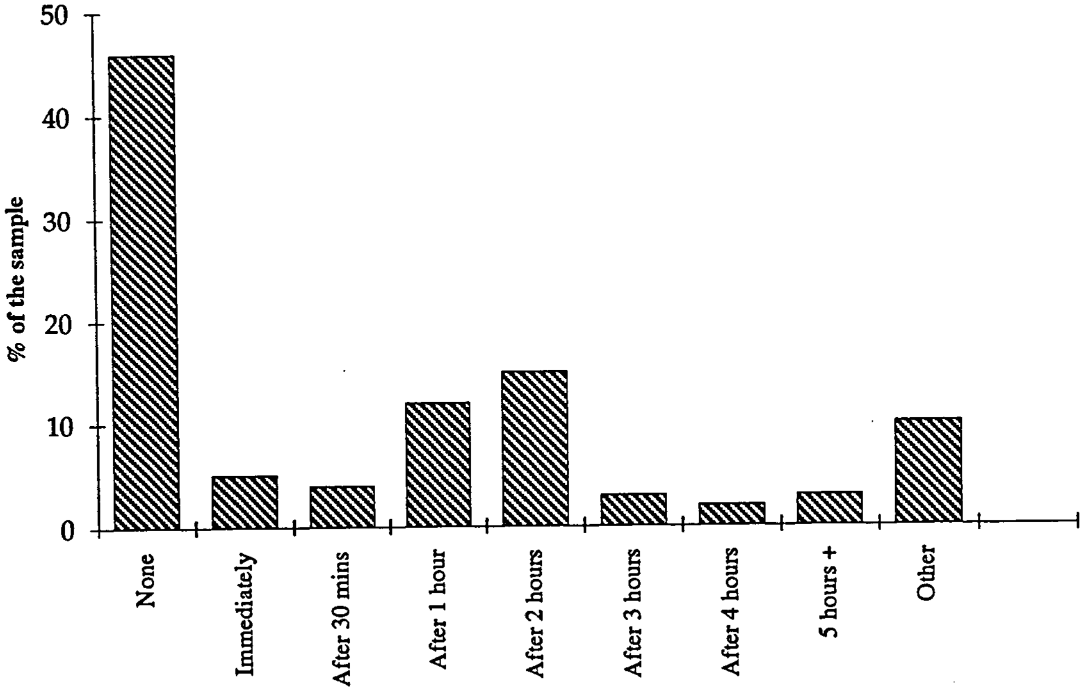


Table 13. Annual mileage of car drivers by age-group and gender with significant differences between gender (n=422).

Age-group	Males (miles) Mean (SD)	Females (miles) Mean (SD)	Significance of F
17-24	9,911 (11,312) (n=30)	9,466 (12,179) (n=29)	NS
25-34	21,058 (19,016) (n=62)	12,028 (10,405) (n=60)	**
35-44	19,782 (17,371) (n=49)	9,615 (9,138) (n=44)	***
45-54	21,496 (17,969) (n=50)	8,632 (13,284) (n=44)	***
55-64	10,044 (7,362) (n=20)	6,567 (6,685) (n=18)	NS
65-74	8,955 (5,824) (n=11)	4,840 (3,376) (n=5)	(a)

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Mileage over the last 12 months positively correlated with both the number of occasions and the total number of days ever absent from work with low back trouble (Table 14). This correlation however, was found to be strong for males only. These correlations were not so for neck and shoulder trouble. Figure 9 illustrates the number of days ever absent from work with low back trouble by annual mileage group for the whole sample of car drivers (males and females together).

Figure 9. Number of days ever absent from work with low back trouble for car drivers according to annual mileage (n=422)

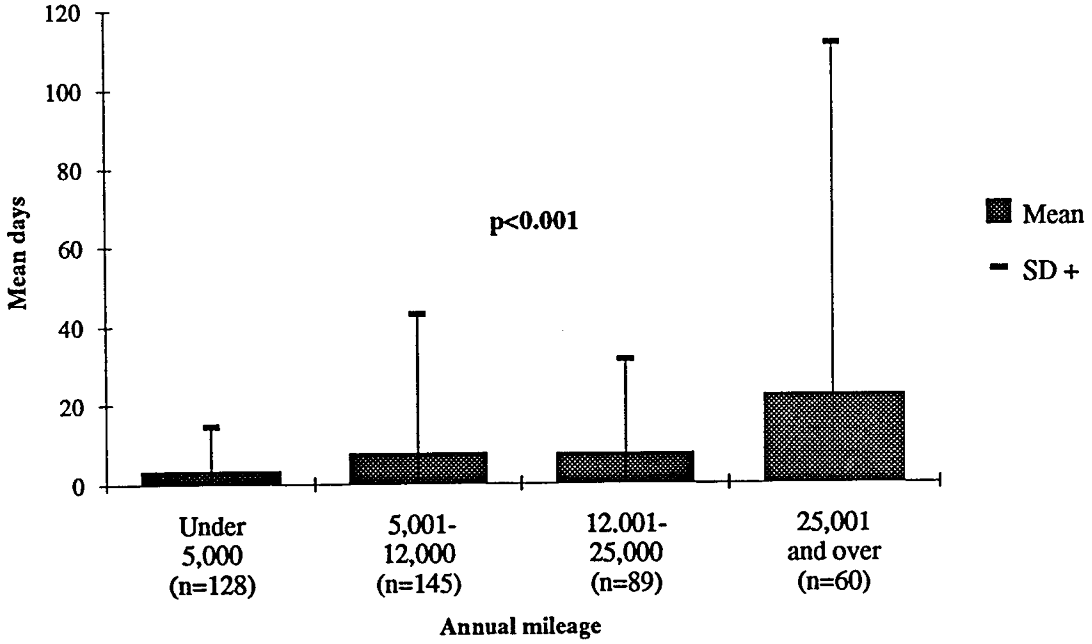


Figure 10. Reported discomfort of car drivers according to number of miles driven over the last 12 months (n=422).

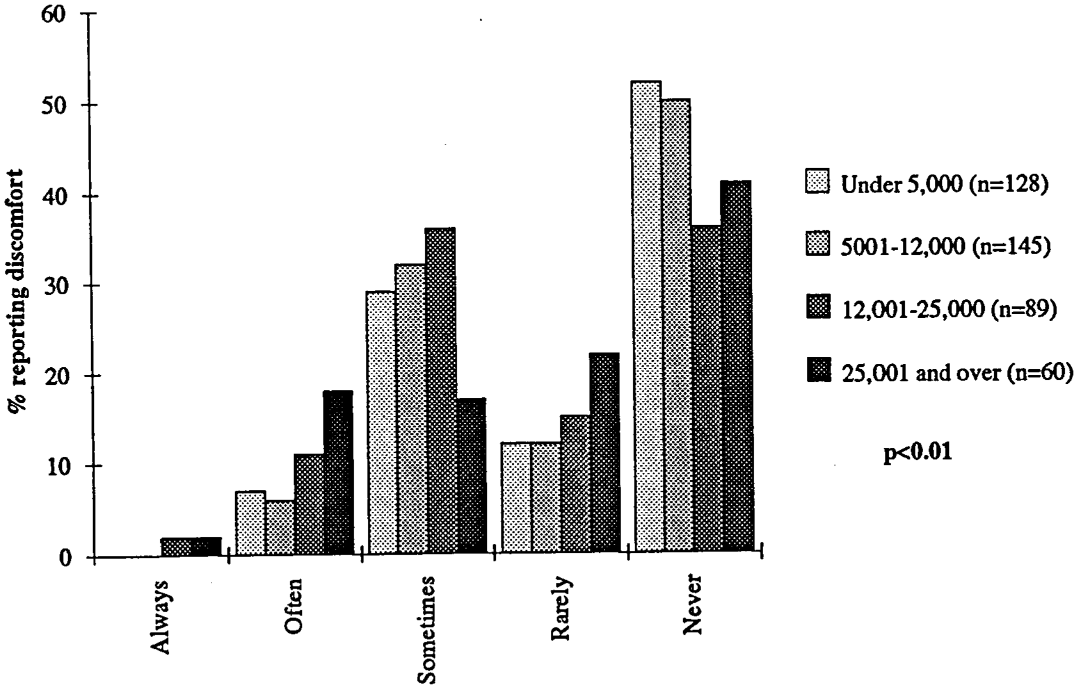


Table 14. Correlation coefficients (Pearson's r) for annual mileage and sickness absence criteria.

Annual mileage - Car drivers			
Criteria	**Whole sample** (n=422)	**Males** (n=222)	**Females** (n=200)
The number of occasions ever absent from work with low back trouble.	.1022 *	.1709 **	.1129
Total number of days ever absent from work with low back trouble.	.1785 ***	.2402 ***	.0752

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Discomfort was more frequently reported with their car with increasing mileage over the last 12 months ($p<0.01$). This is illustrated in Figure 10.

Journey to work in terms of distance and time

Details regarding the work journey for those who drove themselves to work by car are shown in Table 15.

Table 15. Journey to work in distance and minutes taken (n=248).

Journey to work	Mean (SD)	Range
Journey length (miles)	16.88 (27.34) miles	1-200 miles
Time taken (minutes)	28.60 (27.43)	1-210

The length of the journey driven to work in terms of its distance and the number of minutes it took, positively correlated with the length of time the individual had suffered low back trouble in the last 12 months (Table 16). Once again the males showed stronger correlations than the females.

Table 16. Correlation coefficients (Spearman's rank) for journey to work by time (number of minutes) and distance for sickness absence criteria (car drivers).

Work Journey - Car drivers			
Criteria	**Whole sample** (n=320)	**Males** (n=184)	**Females** (n=136)
Total length of time **low back trouble** experienced in the last 12 months.	.1278 * **(time)** .1942 *** **(distance)**	.1582 * **(time)** .2443 *** **(distance)**	.1046 **(time)** .1633 (a) **(distance)**

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Hours and distance driven as part of work

For those whose job involves driving, the number of hours and distance driven as part of their job during a typical week are shown in Table 17.

Table 17. Driving carried out as part of work in distance and hours for car drivers only (n=113).

Work driving / week	**Mean (SD)**	**Range**
Distance (miles)	461.42 (359.71) miles	10-2000 miles
Time driving (hours)	16.07 (11.41)	4-60

The number of hours driven as part of work positively correlated with the number of days ever absent from work with low back trouble (Figure 11 and Table 18) and the total number of occasions ever absent from work with low back trouble Table 18.

Table 18. Correlation coefficients (Pearson's r) for hours driven as part of work and sickness absence criteria.

Criteria	**Hours driven as part of work** Car drivers (n=113)
The number of occasions ever absent from work with **low back trouble.**	.3573 ***
Total number of days ever absent from work with **low back trouble.**	.4072 ***
The number of occasions ever absent from work with **neck trouble.**	.1574 (a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Figure 11. Number of days ever absent from work with low back trouble for car drivers according to hours travelled as part of work (n=113)

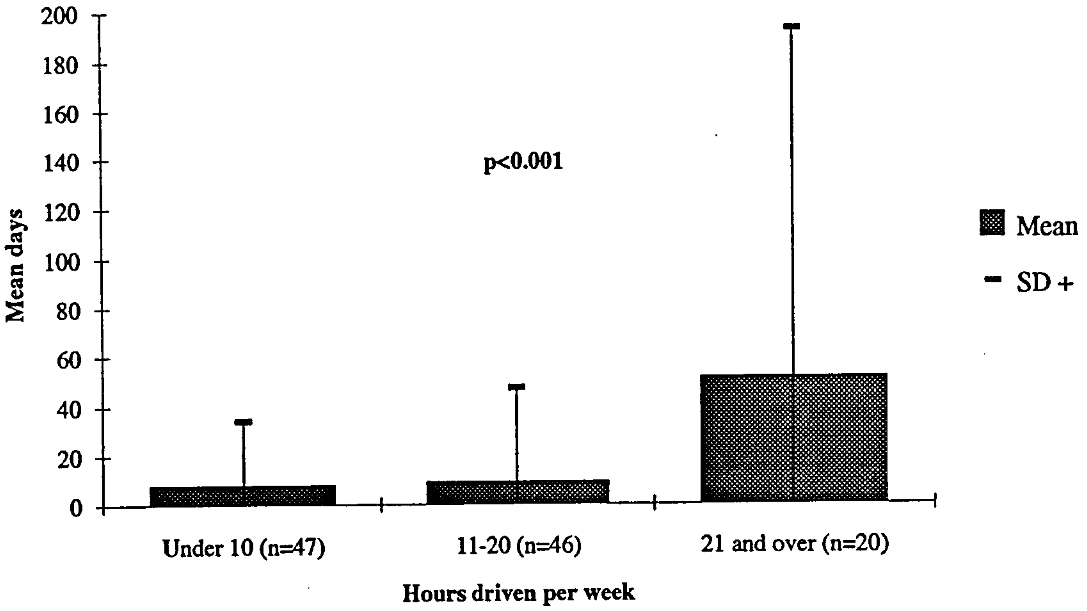
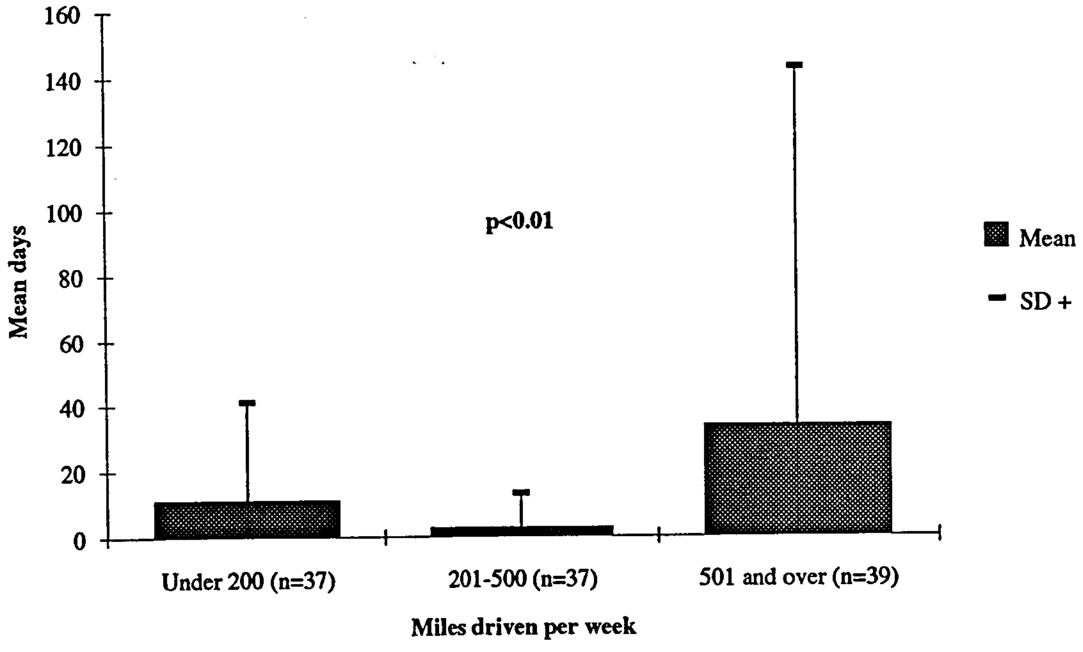


Figure 12. Number of days ever absent from work with low back trouble for car drivers according to distance (miles) travelled as part of work (n=113)



There was also a significant positive correlation with the point prevalence of wrist / hand trouble and the hours driven as part of work for car drivers (Table 19).

Table 19. Correlation coefficients (Spearman's rank) for the hours driven as part of work and the prevalence of wrist / hand trouble.

Wrist/Hand trouble	**Hours driven as part of work** Car drivers (n=113)
Point prevalence (7 days).	.1760 (a)
Period prevalence (12 months).	.2712 *
Severity over the last 12 months.	.1101

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

There were significant positive correlations between mileage driven for work and the sickness absence measures of low back trouble (Table 20 and Figure 12). This difference was approaching significance for neck trouble.

If car drivers who drove as part of their work were compared to those who just drove for social, domestic and pleasure purposes, the former reported more frequent discomfort with their vehicle (p<0.05).

Table 20. Correlation coefficients (Pearson's r) for the distance driven as part of work and sickness absence criteria.

Criteria	**Distance driven as part of work** Car drivers (n=113)
The number of occasions ever absent from work with **low back trouble.**	.2317 *
Total number of days ever absent from work with **low back trouble.**	.2568 **
Total number of days ever absent from work with **neck trouble.**	.1648 (a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

5.4.6 Work Factors

Driving versus sitting at work

The working population of the sample only are now considered. In order to investigate the effect of the number of hours driving, those who drove a car for more than 20 hours / week as part of their work, were compared to those whose work involves sitting for more than 4 hours / day i.e. more than 20 hours / week (Figure 13). There was a significant difference between the two groups for the total length of time low back trouble was suffered in the last 12 months ($p<0.05$), the number of days being higher for the driving group. For example, 36% of the group who drove for more than 20 hours a week for work experienced low back trouble for more than 8 days in the last 12 months, compared with only 16% of the group that sat for more than 20 hours a week at work. However, the total length of time neck and shoulder trouble was suffered in the last 12 months was higher for the sitting group (neck $p<0.05$, shoulder $0.1>p>0.05$)).

Driving versus standing at work

Those whose job involved driving a car for more than 20 hours/week were then compared to a group whose job involved standing for more than 4 hours/day i.e. more than 20 hours a week as part of their work. The number of days ever absent from work with low back trouble (Table 21) and the total number of days low back trouble was experienced in the last 12 months were higher for the driving group ($0.1>p>0.05$). For the latter 36% of the driving group compared with 28% of the standing group experienced low back trouble for more than 8 days in the last 12 months (Figure 13). However the difference between the groups for the number of occasions and days ever absent from work with shoulder trouble (Table 21) was higher for the standing group ($p<0.05$).

Driving versus lifting at work

The same group of drivers were then compared to a group whose job involved lifting 5 kg or more, often (more than 10 times an hour). There were no significant differences between the groups for low back trouble. However the severity of neck trouble i.e. the length of time neck trouble had prevented normal activity in the last 12 months ($p<0.05$) and the length of time shoulder trouble was experienced in the last 12 months ($0.1>p>0.05$) were higher for the lifting group.

Figure 13. Number of days low back trouble experienced in the last 12 months according to driving a car compared with other work tasks (n=376).

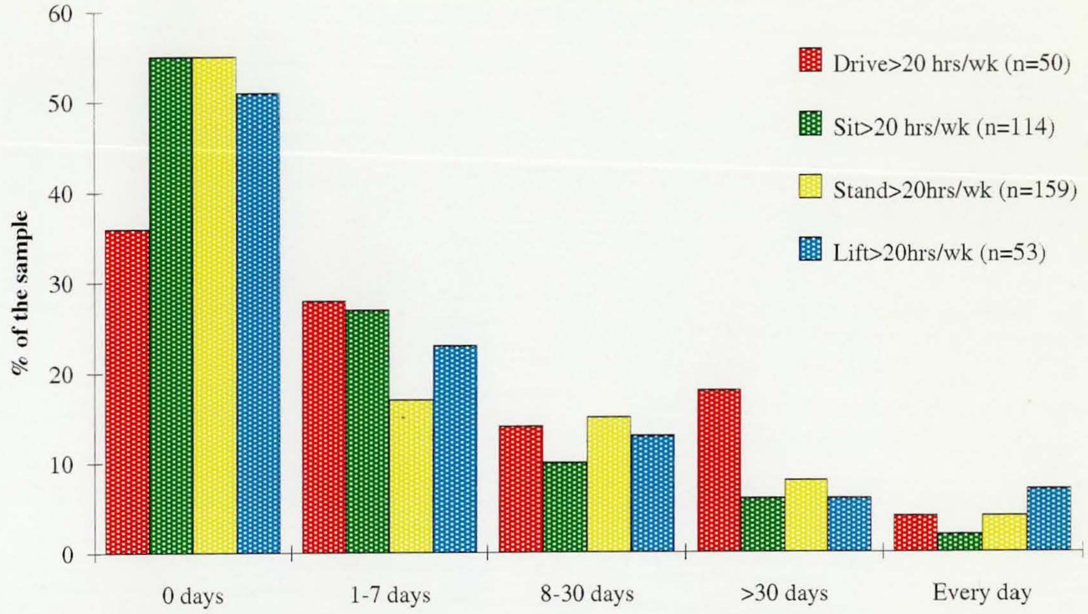


Figure 14. The percentage of superminis (1), small family cars (2) and large family cars (3) with adjustable features.

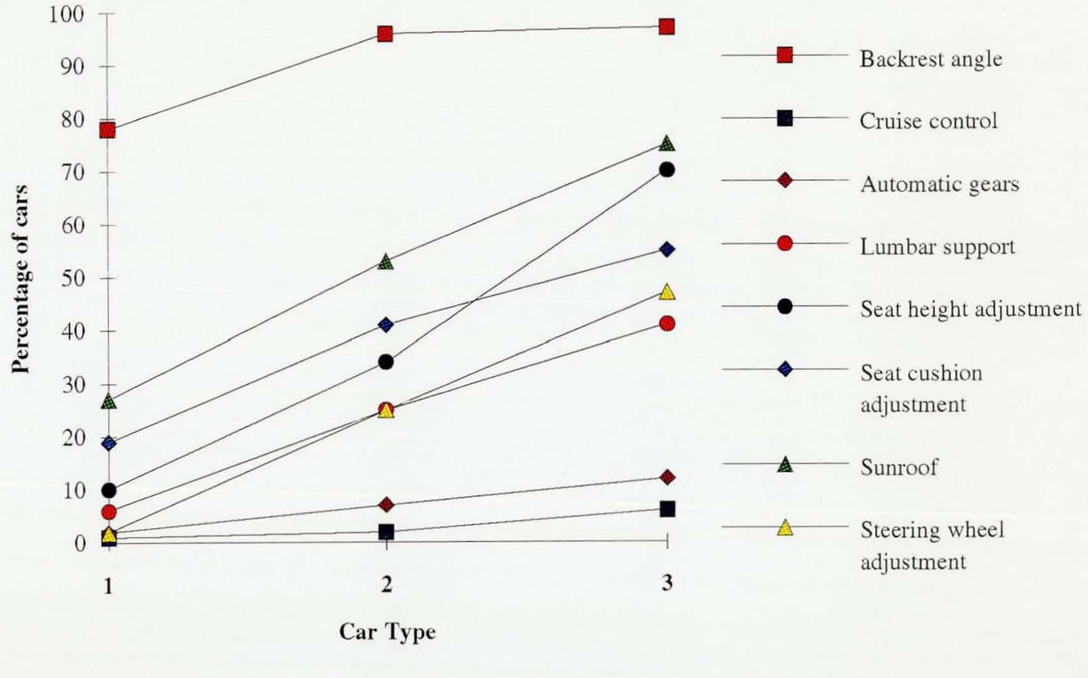


Table 21. Means, standard deviations and significance levels for sickness absence variables according to exposure to standing or driving.

Criteria	**Drive cars more than 20 hours/week as part of their job** Mean (SD) (n=50)	**Stand more than 20 hours / week as part of their job** Mean (SD) (n=159)	Significance
Total number of days ever absent from work with **low back trouble.**	13.28 (39.51)	3.6 (12.94)	(a)
The number of occasions ever absent from work with **shoulder trouble.**	0.02 (.14)	0.11 (.53)	*
Total number of days ever absent from work with **shoulder trouble.**	0.08 (.56)	1.32 (7.08)	*

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Job satisfaction

No significant correlations were found between job satisfaction and any of the sickness absence or prevalence and severity criteria. Males and females also reported very similar levels of job satisfaction.

5.4.7 Postural Factors

Adjustability of the vehicle and sickness absence criteria

- *Lumbar Support*

There was a significantly greater number of occasions ever absent from work with low back trouble for those car drivers without an adjustable lumbar support. This difference was approaching significance for neck trouble (Table 22).

- *Steering wheel adjustment*

There was a significantly greater number of days absent from work with neck trouble in the last 12 months for those car drivers without steering wheel adjustment. This difference was approaching significance for shoulder trouble (Table 23).

Table 22. Means, standard deviations and significance levels for sickness absence criteria and adjustable and non-adjustable lumbar support.

Criteria	**Adjustable lumbar support** (n=112) Mean (SD)	**No adjustable lumbar support** (n=310) Mean (SD)	**Significance of F**
The number of occasions ever absent from work with **neck trouble.**	.07 (.29)	.14 (.48)	(a)
The number of occasions ever absent from work with **low back trouble.**	.31 (.84)	.66 (2.35)	*

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 23. Means, standard deviations and significance levels for sickness absence criteria and steering wheel adjustment.

Criteria	**Adjustable steering wheel** (n=115) Mean (SD)	**No adjustable steering wheel** (n=307) Mean (SD)	**Significance of F**
Total number of days absent with **neck trouble** in the last 12 months.	.03 (.21)	.47 (3.81)	*
Total number of days absent with **shoulder trouble** in the last 12 months.	.02 (.19)	.33 (3.4)	(a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

- Automatic gearbox

There was a significantly greater number of days absent from work with neck trouble in the last 12 months for those car drivers without an automatic gearbox. This difference was approaching significance for shoulder trouble (Table 24).

Table 24. Means, standard deviations and significance levels for sickness absence criteria and automatic gearbox.

Criteria	**Automatic gearbox (n=44)** Mean (SD)	**No automatic gearbox (n=378)** Mean (SD)	**Significance of F**
Total number of days absent with **neck trouble** in the last 12 months.	.00 (00)	.39 (3.44)	*
Total number of days absent with **shoulder trouble** in the last 12 months.	.00 (00)	.28 (3.19)	(a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

- *Cruise control*

There was a significantly greater number of days absent from work with neck trouble in the last 12 months for those car drivers without cruise control. This difference was approaching significance for shoulder trouble (Table 25).

Table 25. Means, standard deviations and significance levels for sickness absence criteria and cruise control.

Criteria	**Cruise control** (n=24) Mean (SD)	**No Cruise control** (n=398) Mean (SD)	**Significance of F**
Total number of days absent with **neck trouble** in the last 12 months.	.00 (00)	.37 (3.35)	*
Total number of days absent with **shoulder trouble** in the last 12 months.	.00 (00)	.26 (3.01)	(a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

- *Other adjustments*

There were no significant differences in sickness absence between the groups for those with and without backrest angle adjustment, seat cushion tilt, seat height adjustment and a sunroof. There were also no significant differences between groups for the following:

- with and without enough headroom.
- pedals in a comfortable and uncomfortable position.
- steering wheel in a comfortable and uncomfortable position.

The total number of adjustment features in the vehicle did not correlate with any of the sickness absence criteria.

Adjustability of the vehicle and discomfort

- Backrest angle

Car drivers whose vehicle had no backrest angle adjustment reported more frequent discomfort in their vehicle than those without ($p<0.01$). There were no other significant differences between the groups i.e. provision or not of an adjustment feature (seat height, steering wheel etc.) for discomfort.

Driving position and discomfort

- Headroom

Car drivers whose vehicle headroom was inadequate, reported more frequent discomfort with their vehicle than those whose headroom was adequate ($p<0.05$, see Table 26).

- Pedal position

Car drivers whose pedal position was poor, reported more frequent discomfort with their vehicle than those with a good pedal position ($p<0.05$, see Table 26).

- Steering wheel position

Car drivers whose steering wheel position was poor, reported more frequent discomfort with their vehicle than those whose position was good ($0.1>p>0.05$, see Table 26).

Table 26. Correlation coefficients (Spearman's rank) for driving position and reported discomfort.

Reported discomfort - Car drivers (n=422)		
Lack of Headroom	**Poor Pedal position**	**Poor Steering wheel position**
.0971 *	.0971 *	.0898 (a)

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Vehicle type

Drivers of superminis (e.g. Fiat Uno, Ford Fiesta), small family cars (e.g. VW Golf, Ford Escort, Fiat Tipo) and large family cars (Fiat Tempra, Vauxhall Cavalier) were selected for comparison between groups. The samples were as shown in Table 27. It can be seen in Figure 14 that the percentage of cars with each adjustment is higher with the larger cars. With regard to subjective opinion on enough headroom, pedal position and steering wheel position the results were satisfactory for all three vehicle groups i.e. more than 90% were satisfied.

Table 27. Descriptive statistics for drivers of superminis, small family cars and large family cars.

Variable	Supermini (n=125) Mean (SD), Range	Small Family Car (n=155) Mean (SD), Range	Large Family Car (n=97) Mean (SD), Range
Age	37.02 (13.73), 18-72	40.21 (13.2), 18-71	40.51 (11.05), 23-73
Adjustments	1.18 (.85), 0-4	2.29 (1.29), 0-6	3.24 (1.43), 0-5
Annual Mileage	9,034 (9984), 20-72,150	12,139 (14,281), 100-124,301	21,734 (18,109), 10-80,000

The severity of neck and shoulder trouble were found to be higher with the supermini and small family car compared to the large family car (Figure 15) for:

- the total length of time neck trouble has prevented normal activity in the last 12 months ($p<0.05$).
- the total length of time shoulder trouble has prevented normal activity in the last 12 months ($p<0.05$).

Differences approaching significance were found between the three groups for the following, but the source of the difference was not so apparent:

- the total length of time low back trouble has prevented normal activity in the last 12 months ($0.1>p>0.05$).
- the total length of time neck trouble has been suffered in the last 12 months ($0.1>p>0.05$).

If subjects who drove these cars as part of their job were considered separately, differences between the groups were found for the following, both showing a greater severity of trouble with the supermini and small family car:

- the total length of time neck trouble has prevented normal activity in the last 12 months ($p<0.05$).
- the total length of time shoulder trouble has been suffered in the last 12 months ($0.1>p>0.05$).

Figure 15. Severity (i.e. preventing normal activity) of neck, shoulder and low back trouble over the last 12 months for drivers of 3 types of car (n=376).

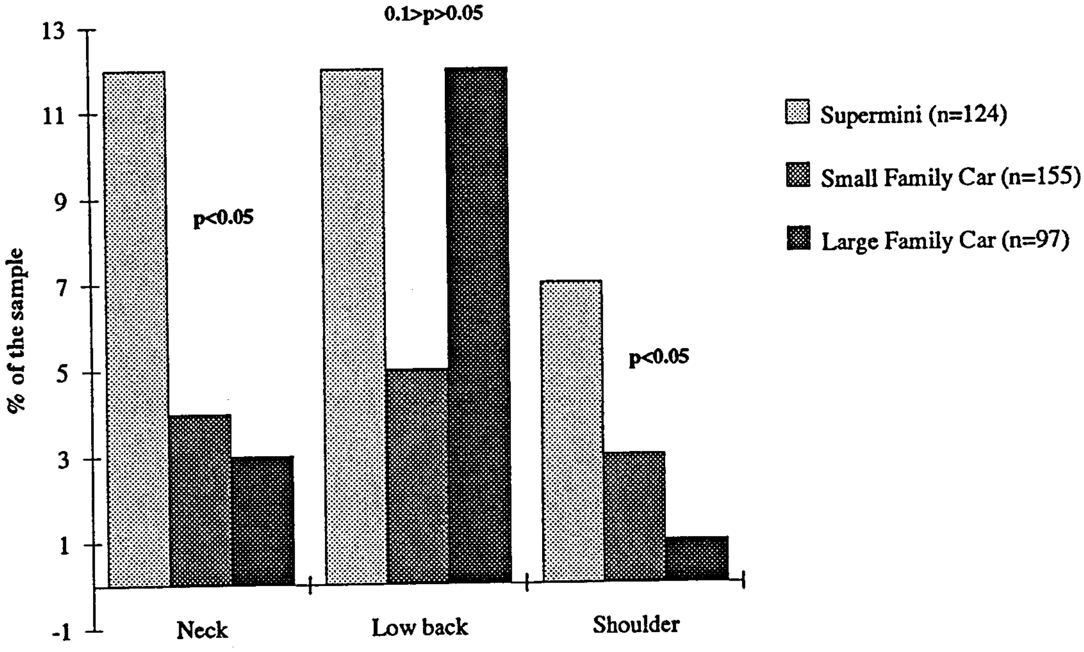
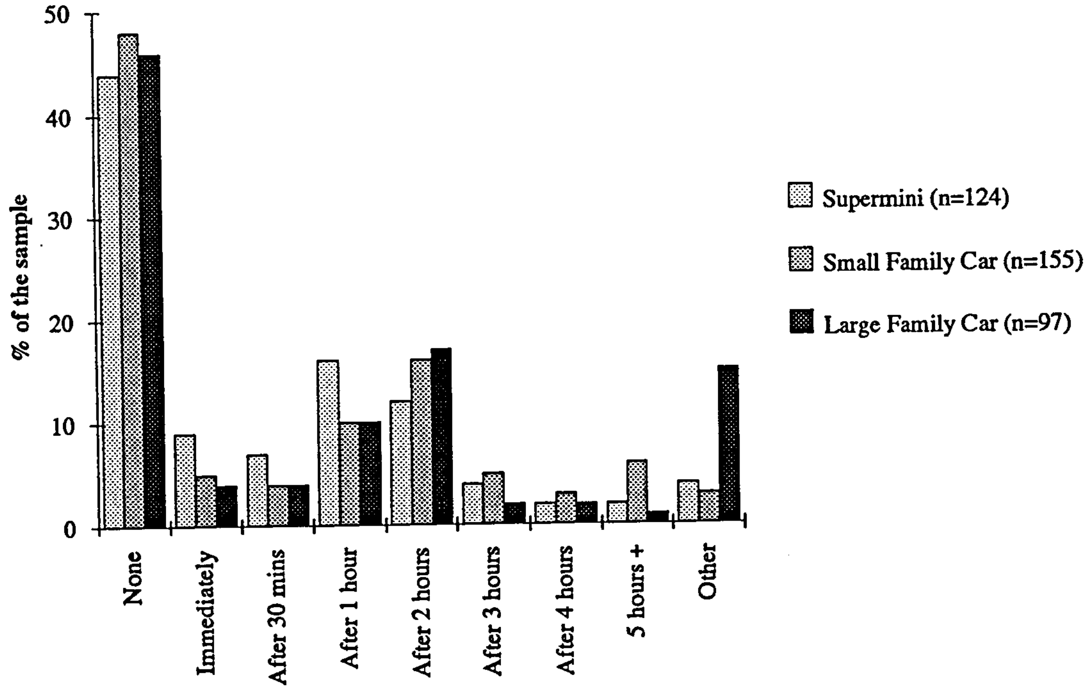


Figure 16. Circumstances under which discomfort occurs according to vehicle type (n=376).



There were no significant differences between the groups for discomfort frequency. The circumstances under which this discomfort was experienced by vehicle type is shown in Figure 16.

N.B. Examples of the category 'others' include 'end of the day', 'stress', and 'end of week'.

5.4.8 Prevalence Odds Ratios

The prevalence odds ratio was used to examine the prevalence data on low back trouble in subjects exposed to significant amounts of car driving compared to those who were not. It can be seen, for example in Table 28, that the odds of subjects who drove cars for more than 10 hours a week as part of work experiencing low back trouble in the last 12 months was 2.84 times higher than those that drove cars for less than 10 hours a week at work. Considering subjects who drove cars for more than 20 hours a week as part of work, the odds for the same condition are similar at 2.66 times higher.

Table 28. Prevalence and prevalence odds ratios for low back trouble for exposure to driving cars.

	Prevalence Odds Ratio				
Low back trouble	Annual mileage >25,000 cf. annual mileage <25,000	Drive as part of work cf. non-drivers.	Drive as part of work cf. social, domestic & pleasure drivers.	Drive >10 hours/week at work cf. those who drive <10 hours/week at work.	Drive >20 hours/week at work cf. those who drive <20 hours/week at work.
Point prevalence (7 days)	1.41	1.34	1.47	1.8	1.96
Period prevalence (12 months)	1.47	1.53	1.49	2.84	2.66
Lifetime prevalence	1.27	1.11	1.28	3.32	2.34
Severity (12 months)	0.83	1.76	0.92	1.5	1.31

The prevalence odds ratios were also calculated in order to examine the affects of lifestyle variables (smoking and sport) and work activity variables (sitting, standing, lifting, vibration and sudden maximal physical effort) on the prevalence of low back trouble (Appendix 3). The variable 'sudden maximal physical effort' had the highest odds for the severity of low back trouble over the last 12 months (odds of 3.20) followed by lifting (odds of 1.76). The odds for lifting were generally lower than those for high exposure to driving for the point prevalence, period prevalence and lifetime prevalence of low back trouble. These odds were 1.26, 1.59 and 1.19 respectively.

5.4.9 Multiple Regression Analysis

In order to further clarify the relative importance of the different variables in contributing to 'days ever absent due to low back trouble' (the dependant variable) it was decided to perform multiple regression analysis. Initially, the decision was taken not to modify the data in any way, for example to transform it into logarithms, so that the interpretation of the results was not made more complex. The aim of the analysis was not just to create the best model but to explore the data sets of car drivers:-

1. Car drivers as part of their job.
2. Social, domestic and pleasure car drivers.
3. All car drivers.

N.B. 1 and 2 are subsets of 3.

The sample of individuals who drove cars as part of their job were considered first. The variables concerned with personal details, sports activity, work activity, having a back accident and exposure to driving were entered into the multiple regression procedure. The regression diagnostics of standardised residuals, leverage, and Cook's distance were used to check that the data fitted the assumptions for multiple regression. Candidates for closer inspection were identified i.e. possible outliers or points of influence, but the author was satisfied that these were genuine values. In this sample only 22% of subjects ever had sickness absence due to low back trouble (1-600 days) and the other 78% had no sickness absence due to low back trouble, therefore attempts to normalise the data were impossible. There was, however, justification for leaving in the outliers as the subjects were all genuine and randomly selected as explained in Section 5.2.

A statistical approach based on adjusted r-squared was used to decide the set of variables for the best fit to the model. Adjusted r-squared is the preferred measure of 'goodness of fit' and attempts to correct the r-squared value to more closely reflect how well the model fits the population. Both sexes were grouped together as gender did not appear to have a significant effect on low back trouble. The best model which accounted for 25.1% of the variance in the sample, involved the variables 'hours driven as part of work', 'having a back accident' and the 'number of cigarettes smoked a day'

(Table 29). The variable 'weight' also improved the model slightly but the effects were insignificant and therefore it was not included in the equation. The Variance Inflation Factor (VIF) values were used as an indicators of multicollinearity, for which Glantz and Slinker (1990) suggested that values exceeding 10 were signs of serious multicollinearity and values exceeding 4 warranted investigation. The low VIF values in this instance (1.237, 1.087 and 1.293) indicated that there were no problems with multicollinearity. However, despite a reasonably good adjusted r-squared (25.09%), it must be remembered that there was some model misspecification (i.e. the data did not fit all of the assumptions for multiple regression). This affects the ability to draw conclusions based on the actual values of the correlation coefficients. Although it was judged, that confidence could be given in the variables selected by the technique as being important in explaining 'days ever absent due to low back trouble' for this sample.

Table 29. Variables entered into the multiple regression equation for 'best fit' of the model to the sample of those who drove as part of their job. The dependent variable is sickness absence ever due to low back trouble.

Variable	**Adjusted r-squared**	**Significant change in F**	**Regression Coefficient (B)**	**Standard Error of B**	**VIF**	**Intercept**
Hours driven at work	.1583	.0000	2.6759	.5363	1.237	
Back accident	.2142	.0035	27.6599	7.8196	1.087	
Number of cigarettes smoked	.2509	.0129	-1.8766	.7419	1.293	-41.8333

The same problems were encountered when this model was tested with the other two sample groups and when it was attempted to build new models with these groups. A sample with a more normal distribution of sickness absence due to low back trouble was required.

To achieve this and to further understand the data, a sample of subjects who had ever been absent with low back trouble (n=115) were extracted from the whole sample (n=600) for examination. This sample is described by gender in Table 30, although both sexes were grouped together for the analysis. The aim now was to attempt to build a correctly specified model (modelling approach). The variables were once again checked for adherence to the assumptions for multiple regression analysis and it was found that by taking the logarithm of total days sickness absence due to low back trouble, the normal probability plot became more linear. No outliers or points of influence were identified in the data. Once again a statistical approach based on adjusted r-squared was used to decide the set of variables for the best fit to the model.

The best model accounted for 12.1% of the variance with the variables 'age', 'having had a back accident' and 'having a job which involved sitting, often' (Table 31). The VIF values were once again low (1.046, 1.055 and 1.052) indicating no problems with multicollinearity.

Table 30. Description of the sample of subjects who have had sickness absence due to low back trouble by gender.

Driving group	Percentage of the sample		
	Males (n=60)	Females (n=55)	Whole sample (n=115)
Non drivers	12	24	17
Drive as part of work	45	18	32
Social, domestic and pleasure drivers	43	58	51

Table 31. Variables entered into the multiple regression equation for 'best fit' of the model to the sample of subjects (n=115) with sickness absence ever due to low back trouble (logarithm = dependent variable).

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
Age	.0478	.0108	.0125	.0044	1.046	
Back Accident	.0976	.0082	.3228	.0044	1.055	
Sitting at work 'often' (not drivers)	.1209	.0490	.0496	-.1792	1.052	.3391

5.5 Discussion

The discussion could include many issues from the large amount of data that were collected, but for the purpose of this report it will focus on the main findings relevant to car seat design.

The sample of subjects from the general public consisted of males and females, a wide range of age groups, annual mileage, vehicle types, heights, weights, occupations etc. The author has no reason to believe that the sample is not representative of a range of non-drivers, low and high mileage drivers and people who drive as part of their job in Great Britain.

Some of the general descriptive statistics in the data were compared to other sources to check for inconsistencies in the sample. The lifetime prevalence of low back pain was slightly lower in this study (56% of men and 57% of women) than that of Walsh et al (1989) who found 64% of men and 61% of women and Biering-Sorensen (1983) who found an even higher lifetime prevalence of 68% for both men and women. The reasons for the slight difference could be that in Walsh et al's (1989) study the term 'low back pain' was used instead of 'low back trouble' and that only one geographical area was studied which had only four main sources of employment in the area (agriculture, a paper mill, a silk mill and service industries). Also, perhaps despite their high response rate (80%), the questionnaire could still have primarily been returned by individuals with low back pain. In the study by Biering-Sorensen (1883) the subjects were older (over 30) and therefore not all age groups were reflected in this figure for lifetime prevalence. These studies also highlight the problems of comparing data without knowing the specifics of study design.

According to the Yearbook of Labour Statistics (1993), 45% of the population (aged 16 and over) of the United Kingdom were employed in 1992, which was made up of 55% males and 45% females These figures were comparable with those from the General Household Survey (1992) of 54% males and 46% females in 1992. The sample from the general public survey consisted of 72% in employment, much higher than the national figure. Reasons for this increase could be due to the proportion of part time workers versus full time workers and the fact that all the subjects interviewed were ambulant in public places.

5.5.1 Exposure to Driving

The results from this study clearly indicate that exposure to driving a car in terms of annual mileage, distance driven to work and time taken to drive this distance have an effect on sickness absence due to low back trouble. For example, Figure 9 shows that for the whole sample of car drivers the mean number of days ever absent from work with low back trouble was 22.4 days (SD 111.26) for high annual mileage drivers (25,001 miles and over) compared with 3.3 days (SD 14.72) for low annual mileage drivers (under 5,000 miles). The correlations between annual mileage and the number of occasions and days ever absent from work with low back trouble were even stronger if males were considered separately (Table 14). This was thought to be due to the considerably higher exposure to car driving of the males; a mean of 17,777 miles (SD 16,871), compared with 9,707 miles (SD 10,796), p<0.001 for the females.

The car journey driven to work in terms of distance and time could indicate regular daily exposure and it was found that the length of time low back trouble was experienced (not necessarily days absent) in the last 12 months was higher for those drivers with longer journeys.

Considering those whose work involved driving a car as part of their job, the results again clearly showed that the number of occasions and days ever absent with low back trouble was higher in those with the greatest exposure to driving. Figure 11 shows that those who drove for more than 20 hours a week as part of their job had a mean number of days ever absent with low back trouble which was six times higher than those who drove less than 10 hours a week as part of their job (51.4 days, SD 192.9 compared with 8.1 days, SD 34.2). Figure 12 shows that those who drove more than 500 miles a week as part of their job had a mean number of days ever absent with low back trouble nearly three times higher than those who drove less than 200 miles as part of their job (33.7 days, SD 192.9 compared with 11.2 days SD 41.18).

Initially, car drivers 'as part of their job' were compared with 'social, domestic and pleasure drivers' and non-drivers. No significant differences were found between the groups for any of the prevalence data but individuals who drove cars as part of their job had more occasions and days ever absent with low back trouble than the other two groups. For example, 16.2 (SD 67.3) days ever absent with low back trouble compared with 5.6 (SD 5.6) days for 'social, domestic and pleasure' drivers and 1.7 (SD 4.7) days for non-drivers. However, in this survey the sample of non-drivers was considerably younger than the other two groups, they smoked more cigarettes and a higher percentage of them were unemployed (see Appendix 4). Individuals choose not to drive for many reasons for example, age, disability or financial difficulties all which could have a confounding effect on the data. Also, exposure to driving in the sample covered a good range, from 10-2000 miles a week and from 4-60 hours a week. This all lead to the decision concentrate on low / high exposure to driving, rather than exposure / non-exposure.

In the multiple regression analysis the variable 'hours driven as part of work' was selected along with the variables 'having a back accident' and the 'number of cigarettes smoked a day' as being significantly important in explaining the 'number of days ever absent with low back trouble' for the sample of those who drove cars as part of their job. Despite some model misspecification, this was not due to error in the data and therefore it was judged that the number of hours driven as part of work was likely to have an influence in predicting sickness absence due to low back trouble.

Considering the prevalence odds ratios, it can be seen in Table 28, Section 5.4.8 that the odds of subjects who had high exposure to driving experiencing low back trouble were particularly high for period and lifetime prevalence. For example, the odds ratio for subjects who drove for more than 20 hours a week as part of work experiencing low back trouble in the last 12 months was 2.66 times higher than for those that drove cars at work for less than 20 hours a week at work. Interestingly, the same odds for those who drove for more than 10 hours a week as part of work were similar (odds of 2.84). However, this value does also include the subjects who drove more that 20 hours a week at work. These figures appear to be comparable with the results of other studies, although exact comparison is not possible. Kelsey and Hardy (1975) questioned subjects in detail about their occupational histories including the tasks that each job involved and they were able to compare this with the details about when their symptoms for acute herniated lumbar disc began. They calculated the estimated relative odds, which is known to approximate the relative risk of the disease i.e. an acute herniated lumbar disc, when the incidence of the disease is low. They found that comparing cases to matched controls, if a male had a job where he spent more than half his time in a motor car he was 2.75 times more likely to develop an acute herniated lumbar disc. This assumption was not possible with the data from the general public survey as the condition of low back trouble is known to have a high incidence. Walsh et al (1989) derived risk estimates of low back pain for exposure to an activity compared to non-exposure and found that the relative risk for males driving a car for more than four hours a day at work was 2.1, whereas for sitting for more than two hours a day it was 1.3 and for lifting weights of 25 kg or more it was 1.9. Finally Pietri et al (1992) found that the odds ratios for having low back pain in the last 12 months increased with exposure to driving; 1.5 for driving a car 15-19 hours a week, 2.0 for 20-24 hours a week, and 2.1 for more than 25 hours a week.

These results therefore support the findings of other authors. Frymoyer et al (1983) and Damkot et al (1984) also identified exposure to motor vehicles (in terms of hours driving per week) as significant risk factors for low back trouble. Higher reported sickness absence due to low back trouble is also of concern in the light of the study carried out by Kelsey and Hardy (1975) described previously. The risks also appear to be higher for similar exposures; driving a car for more than half their working day (Kelsey and Hardy, 1975), more than 20 hours a week (Pietri et al, 1992) and more than four hours a day (Walsh et al, 1989).

Discomfort was reported in at least one body area by 54% of car drivers. This is comparable with the survey of 1000 drivers by Porter et al (1992), where 53% of the sample reported some discomfort. Figure 10 shows an increased frequency of reported discomfort with higher annual mileage. It can be seen that 20% of high mileage (25,001 miles and over) drivers 'always' or 'often' had discomfort with their car compared with 7% of low mileage (under 5,000) drivers. Figure 7 clearly shows that the most frequently reported discomfort areas were the low back (26%) and neck (8%). This is also comparable with the work carried out by Porter et al (1992) where the figures were as follows; low back (25%) and neck (10%). Discomfort as discussed in Chapter 2.3 could be a result of the constrained posture caused by the driving workstation. Discomfort in a car seat could also have serious consequences i.e. Pietri et al (1992) found that car sear discomfort was a risk factor of low back pain (odds ratio 2.1 compared with 1.0 for a comfortable car seat).

5.5.2 Comparison of Driving with Other Working Postures

Those whose job involved driving a car were compared with three separate groups; those whose work involved sitting (not driving) for a large part of the day, a group whose job involved standing for a large part of the day and finally a group whose job involved lifting for a large part of the day. The results clearly indicate that driving a car can be as detrimental as sitting and standing postures with regard to low back trouble. Figure 13 shows that 36% of the group who drove for more than 20 hours a week for work experienced low back trouble for more than 8 days in the last 12 months, compared with only 16% of the group that sat for more than 20 hours a week at work. Car drivers who drove for more than 20 hours a week for work have also had nearly four times as many days ever absent from work with low back trouble than the standing group (13.28 days, SD 39.51 compared with 3.6 days, SD 12.95, $0.1>p>0.05$), however the standing group did have more occasions and days absent with shoulder trouble. Considering only the sample of subjects who had actually ever had days absent with low back trouble, 'having a job which involved sitting at work, often' (not driving) was chosen as being predictive of the logarithm of sickness absence due to low back trouble along with 'age' and 'having a back accident' in the multiple regression analysis. Although only 12% of the variance was explained by these three variables, having a job which involves 'sitting at work, often' may be considered to have a slight influence as a possible predictor of days absent with low back trouble. Comparisons with the lifting group showed no significant differences with regard to low back trouble, but neck trouble prevented normal activity for a greater number of days in the last 12 months with the lifting group.

Once again these results generally agree with findings in the literature. Kelsey and Hardy (1975) investigated prolonged sitting and found that the relative risk of acute herniated lumbar disc whilst driving was twice as high as sitting in a chair regardless of the type of chair. As mentioned previously, Walsh et al (1989) derived risk estimates of low back pain for exposure to a work activity compared to non-exposure and found that the relative risk for males sitting for more than two hours a day was 1.3 compared with 1.2 for walking or standing, 2.1 for driving a car more than four hours a day and for lifting weights of 25 kg or more, it was 1.9.

These results clearly show that the effects of the physical demands of the driving task as described in Section 2.3 should be taken seriously, particularly with the view to reducing sickness absence due to low back trouble. Driving allows very little opportunity for postural variance, a requirement which and Akerblom (1948), cited in Keegan (1953) felt essential for comfort in a seat.

5.5.3 Adjustability of the Car

The improved postures and freedom of movement permitted by an adjustable lumbar support, adjustable steering wheel, cruise control and automatic gearbox appear to have a beneficial relationship with the sickness absence criteria. For example:

- drivers of cars which had an adjustable lumbar support had less occasions ever absent with low back trouble than those without this feature (0.7 days, SD 2.35 compared with 0.3 days, SD 0.84). The presence or absence of an adjustable lumbar support was the only feature that had an effect on low back trouble.
- drivers of cars with steering wheel adjustment, or an automatic gearbox, or cruise control had less days absent from work with neck and shoulder trouble in the last 12 months than those drivers without these features. For example, drivers without steering wheel adjustment had 0.33 (SD 3.4) days absent from work with shoulder trouble in the last 12 months compared with only 0.02 days (SD 0.19) for car drivers with steering wheel adjustment (Tables 28, 29 and 30 for the values).

The lower sickness absence due to neck and shoulder trouble is probably due to less postural constraints arising with steering wheel adjustment and an automatic gearbox. Cruise control is likely to be fitted mainly to automatic cars and so is not necessarily a direct benefit. Similarly, cars with an adjustable steering wheel and automatic gearbox probably also have power steering, which considerably reduces the physical workload on the neck and shoulders. It could also be as suggested by Rebiffe (1980) that features such as an automatic gearbox or power steering are more important for the freedom they give the driver to change his posture, than to decrease muscle activity.

The small percentage of drivers who reported not enough headroom (7%), poor pedal position (10%), poor steering wheel position (5%) and no backrest angle adjustment (9%), reported significantly higher frequencies of discomfort with their car. These judgements were likely to be underestimates as they were made away from their vehicle and also not by experts in posture. Again the poor postures and biomechanically inefficient movement directions created being clearly the most probable causes of this discomfort. No differences were found with these subjects for any of the sickness absence measures.

When the three most common vehicle types were compared (supermini, small family car, large family car), it was found that, despite drivers of the large family car being of a slightly older age group and having a considerably higher mean mileage, the number of days being prevented from carrying out normal activity due to neck or shoulder trouble was higher for drivers of the supermini and small family car. Figure 15, for example shows that 12% of drivers of superminis, compared with 3% of drivers of the large family car had neck trouble which prevented normal activity in the last 12 months. This could be hypothesised to be due to the higher mean number of adjustments on the large family car (3.2 adjustments, SD 0.85 compared with 1.18 adjustments, SD 0.85). A greater number of the large family cars also had cruise control and automatic gears (and possibly power steering) reducing the load on the neck and upper body. The fact that 12% of drivers of the supermini and 12% of drivers of the large family car had low back trouble preventing normal activity in the last 12 months, could be explained by the low number of adjustments in the former and the very high annual mileage (21,734 miles, SD 18,109 compared with 9,034 miles, SD 9,984) of drivers of the latter. Just under half of the large family cars (41%) had an adjustable lumbar support, the effectiveness of which must be questioned for these high mileage drivers. Many such lumbar supports do not have height adjustment as recommended by Porter and Norris (1987).

5.5.4 Personal Details

Having shown a clear association between driving and low back trouble it was necessary to investigate some of the possible confounding factors which could also have an influence.

No significant differences were found between the sexes for any of the prevalence or sickness absence measures of low back trouble in this study, although in the literature Jonsson and Ydreborg (1985) found that males had a higher prevalence of low back trouble than females, whereas Reisbord and Greenland (1985) found that females had a lifetime prevalence of low back pain which was 4% higher than males, and Johansson (1994) found that females had a significantly higher frequency of reported musculoskeletal troubles related to present work in the neck, shoulders and knees. Reasons for gender differences were put forward by Reisbord and Greenland (1985) as being the fact that females have to cope with childbearing, they have multiple role obligations, different anatomy and responses to stress. These contrasting results from the literature and the fact that males had a considerably higher mean mileage than women (18,203 miles, SD 21,643 compared with 6,838 miles, SD 10,110), lead to the separate analysis of males and females in the general public survey whenever possible. It was found that females in the general public survey had a significantly higher point prevalence, period prevalence and severity of neck, shoulder, upper back and wrist / hand trouble than males. A reason for this could be that more females worked in jobs which were classified as clerical and related (18% compared with 2%) and consequently were perhaps exposed to high levels of keyboard work. The former result was also supported in the literature by the same study by Jonsson and Ydreborg (1985) although in this case no reasons were put forward as to why this should be.

There were no statistically significant relationships between age and the prevalence of, or sickness absence with, low back trouble, nor did exposure to driving correlate with increasing age. It can therefore be assumed that the effect of age on driving and low back trouble in this sample is minimal, as also reported by Reisbord and Greenland (1985), Waddell (1987) and Burton et al (1989). However the prevalence of musculoskeletal troubles of the large joints such as the hips, ankles and elbows was found to be higher with age. In the study by Porter et al (1992) however older drivers reported less low back discomfort with their cars than younger drivers. Interestingly, it was found that the price of the car and the drivers age were positively correlated ($p<0.001$) and that drivers of cars with more luxury features such as an automatic gearbox were older. This lead the authors to suggest that age may be secondary to the price and so the specification of the car.

When only the sample of subjects who had ever had sickness absence due to low back trouble were examined using multiple regression analysis, 'age' was one of three variables selected as being important in predicting the logarithm of total days sickness absence due to low back trouble. Despite a correctly specified model, 'age' accounted for just 4.78% of the variance and therefore was judged only to be of slight importance in explaining this data set.

For males only, the body mass index does seem to be related to the number of occasions and days ever absent from work with low back trouble. As the body mass index in males did not show a significant correlation with exposure to driving, it is therefore unlikely to be a major cause of low back trouble in high mileage drivers. Also as may be expected (as it is a weight bearing joint), the body mass index was found to be related to the point prevalence, period prevalence and severity of knee trouble although again only for males.

Some authors (Frymoyer et al, 1983; Waddell, 1987; Biering-Sorensen et al, 1989 and Frymoyer and Cats-Baril 1991) reported an association between cigarette smoking and low back trouble, but considering the whole sample no significant correlations were found. However when smokers were compared to non-smokers, they were absent from work with neck trouble on more occasions and for a greater number of days than non-smokers. It is difficult to hypothesise as to why this should be the case. Also, in the multiple regression analysis for the sample of car drivers who drove as part of their job, the 'number of cigarettes smoked a day' was one of the three significant variables selected as being important in predicting the variable 'days ever absent with low back trouble': The three variables together explained 25.1% of the variance in the data. Despite some model specification (i.e. the data did not fit all of the assumptions for multiple regression analysis), this was not due to error in the data and therefore it was judged that the latter statement was likely to be true.

The number of hours that ten 'risk sports' (i.e. high risk for neck and back injuries, Porter and Porter 1990) were participated in showed a significant positive correlation with days ever absent with low back trouble but for females only. This reason for this is not known, as out of the ten 'risk sports' females reported more hours than males for only two of them, high intensity aerobics and horse riding. With the sample of males, there were correlations with the ten 'risk sports' and the length of time neck and shoulder trouble prevented normal activity (work and leisure) in the last 12 months. Males participated in significantly more hours of 'risk sports' (1.46 hours SD 2.63, compared with 0.76 hours SD 1.62, $p<0.001$) and it is likely that neck and shoulder injuries would affect participation in demanding sports such as rugby, squash and football. However, the number of hours these sports were participated in did not show a significant correlation with exposure to driving and therefore the confounding due to 'risk sports' was likely to be minimal. Frymoyer et al (1983) also concluded that sports activity had a minimal effect on low back pain.

There were no significant relationships between job satisfaction and any of the sickness absence or prevalence measures. Most of the sample were generally satisfied with their job, with only 12% reporting that they 'would like a change'. It could be argued that a more thorough questionnaire such as described by Warr et al (1979) could have given a different result, but as already discussed this was too lengthy and threatening for a public interview.

This survey work is summarised along with the police survey in Chapter 7.

Chapter 6 The Police Survey

6.1 Aims

Following concerns expressed by the Occupational Health Department of Sussex Constabulary, of sickness absence levels due to low back trouble (particularly with those officers who drove as part of their job), it was decided to compare two groups of police officers with differing levels of exposure to driving, with regard to sickness absence and prevalence data related to musculoskeletal troubles.

6.2 Sussex Constabulary

The structure of Sussex Constabulary, the shift system and the reporting of sickness absence are described in Appendix 5.

6.2.1 Police Ill Health

The increasingly difficult task of law enforcement and the pressures of such work have generated some academic interest in the health and well being of police officers. The concept of stress among police officers is well documented. For example, a study by Cooper et al (1982) highlighted personality type, style of organisational management and environmental factors as significant predictors of stress related illness. A study by Alexander et al (1991) acknowledged the fact that parts of policing duties were intrinsically unpleasant and stressful, but the results of their survey clearly pointed to organisational and managerial practices as more important sources of dissatisfaction, stress and ill health. Information about health was mainly from studies carried out in the United States. Richards and Fell (1975) found that police officers in the United States had a greater incidence of health problems (not specified) than other occupations and in Hurrel et al's (1984) survey of 2,000 US police officers, the number and types of health disorders reported by these officers over a six month period was similar to those found in the general public over a twelve month period. Assumptions that British police officers were similarly prone cannot be made, but annually increasing absence rates in the United Kingdom suggested that epidemiological data regarding health are urgently needed.

6.2.2 Sussex Police SIMS Database

It was intended to use SIMS (Sickness Information Management System) in order to look at the sickness absence data of police officers who drove for a large part of the day compared to those whose jobs involved different tasks, for example walking or sitting at a desk. This computer database was used to produce monthly statistics of sickness absence data from the different police divisions or departments of Sussex Constabulary. However, after many visits to Sussex it became apparent that its use was going to be very limited for the following reasons:-

1. The database was inaccurate. For example, the term 'lumbar' could not distinguish between pain in the mid or low back. Bruising or skin problems could also be coded under this category. 'Burn-out' of police officers was also often recorded under this category.

2. The database was not very interactive. Any investigative analysis, for example the exact cause of an injury or previous occupation, required a manual search of the individual officer's file in the personnel department. Access to these files was not possible.

3. Data regarding work duties and other potential confounding factors were not available on the database.

4. Approximately 1000 civilians were employed by Sussex Constabulary in a variety of different occupations, for example secretaries, medical workers and traffic wardens. No civilian records were stored on the database so any comparisons with police officers would not be possible.

6.3 Development of the Sample Groups

Sussex Constabulary is divided into 15 divisions representing different geographical areas together with Headquarters (HQ) and Traffic Division. The divisions consist mainly of Patrol Officers (front line officers) but may include some specialist staff such as Special Branch and Criminal Investigations Division (CID). Civilians for example administration staff, mechanics, secretaries and medical staff were also employed by the police service. It was considered that risk from assaults was an important confounding variable with police officers which should be controlled for in the selection of any groups for the study. Following much informal discussion with Sussex Constabulary, the eventual selection of the two main groups of officers for comparison was dependant on numerous practical, political and work issues such as:-

1. CID, although a good example of varied working postures each day, were an extremely difficult group to 'capture' for interview.
2. Control room work was highly pressured with staff sitting all day, but many already had back complaints which they felt were due to poor seats.
3. Patrols such as Brighton and Hastings had a high risk of injury from assault.
4. Patrol officers in general do numerous duties such that it would be difficult locating the 'drivers'.
5. Both groups should have low risk from assault.
6. Both groups of police officers should also have similarities between the groups (same shift system, pay system, method of reporting sickness absence, same geographical area etc.) and will have been with that division for a minimum of six months.

The sample groups eventually selected are described below:-

a) Sample group 1 (the study group).

This group consisted of 105 Traffic Division police officers. These officers were concerned with all aspects of road safety. Their duties included dealing with road traffic accidents, road blocks and traffic offences such as speeding. They should not be confused with 'Panda car' patrols, whose officers respond to emergency calls and carry out a huge variety of general policing duties including breaking up fights or making arrests. Police officers had usually completed 5-6 years service before choosing the speciality of Traffic Division and they then usually stayed at the same base for the rest of their police career. In the past Traffic Division had been considered an 'elitist' division attracting tall, white, young men who liked fast cars. Efforts have been made to attract women and different ethnic groups and there is now no height restriction, however the nature of the job requiring cleaning cars every day and basic car maintenance still mainly attracts men. Another attraction to this division was the number of courses the officers attended; Basic Legislation Course (5 weeks); Advanced Driving Course (4 weeks); Mechanics Course (3 weeks) and specialist courses for example Accident Investigation. They tend to use the same car (or motorcycle in some cases) and drive or sit in a vehicle all day. The cars were replaced after 3-3.5 years, but the seats were only replaced if there was obvious damage.

b) Sample group 2 (the control group)

The control group consisted of 95 officers from Gatwick patrol and Headquarters (HQ). It was hoped to use only officers from Gatwick patrol however practical difficulties lead to some interviews being carried out with officers from HQ. Because of the difficulties obtaining a perfect control group, it was decided that one of the main criteria for selection would be that their daily tasks were varied and that one particular activity was not carried out all day, every day. According to Pheasant (1992b) people who are free to vary their posture and stand at sit at will have a very low prevalence of low back pain. The control groups duties were generally light and included security, walking 'on the beat' at Gatwick, giving directions, some driving, training and light administration duties. Most police officers have to do some driving but no individual in this group did more than ten hours driving per week for work. All police officers in Sussex Constabulary have to work at Gatwick for a minimum two year period and generally it is considered to be 'quiet' with a lot of routine work.

6.4 Procedure

The author and an Occupational Health Nurse trained in the interview technique carried out all the interviewing of the 200 police officers in Sussex, which took place between July and November 1993 (inclusive). The long time period was necessary because of the difficulties encountered travelling to different police stations and working around the different shift systems, emergency calls and other duties. All police officers (as defined by the sample groups in Section 6.3), available and on duty at the time of interviewing at a particular police station were interviewed. This also included some police motorcyclists from Traffic Division who were interviewed for two main reasons. Firstly, so as not to alert the police officers as to the precise reason for the study and secondly the Occupational Health Nurse at Sussex Constabulary was interested in the data from this group. The selection was random as it was not known who would be available and which shift would be on duty. The Chief Inspector of Sussex Constabulary and the individual police sergeants of the different police stations gave their permission to carry out the interviews, but individual officers were not told the actual reason for the study.

6.5 Results

See Chapter 5.3 for a description of the statistics used. Analyses of the data regarding 'vehicle type' were not carried out because the majority of Traffic Division car drivers drove the same vehicle.

6.5.1 Personal Details

The sickness absence and prevalence data for the whole sample of police officers (including drivers of other vehicles) is shown by group in Appendix 6. The prevalence data are illustrated graphically in Figure 17. It can be seen that the only significant differences between the two groups were for period prevalence (12 months) of shoulder trouble and the severity of wrist / hand trouble, the trend in both cases being a higher percentage for Traffic Division.

Age and gender

The age distribution of the whole sample is described by the two sample groups in Table 32. There were only five females (one from Traffic, four from Gatwick and HQ) in the whole sample. They were not considered separately as were not represented in large enough numbers and they were not removed from the sample as they did not appear to be outliers or significantly affect the data.

Table 32. The age distribution of the whole sample (n=200) by group.

Group	Mean (SD)	Age Range
Whole sample (n=200)	36.57 (8.20)	21-60
Traffic (n=105)	36.59 (7.44)	23-54
Gatwick & HQ (n=95)	36.54 (9.01)	21-60

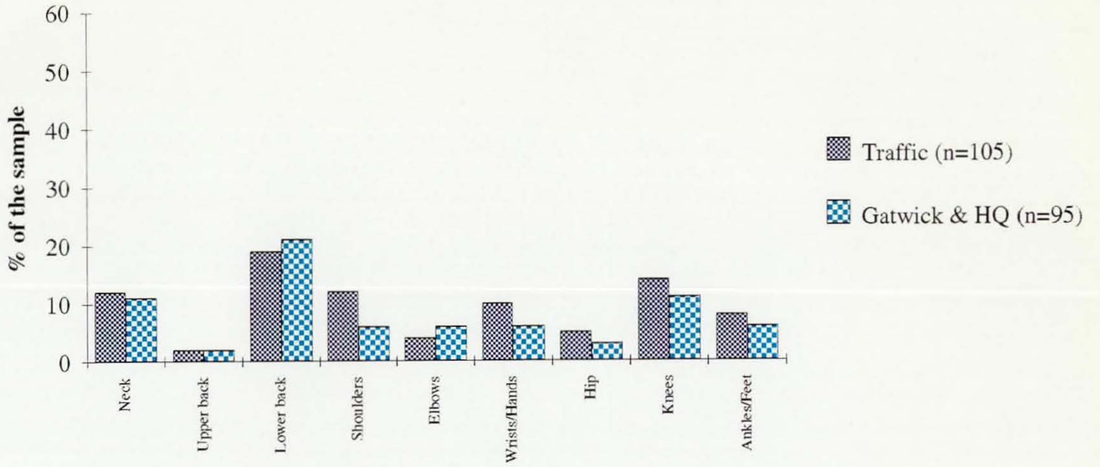
There was a positive correlation approaching significance (0.1>p>0.05) between age and the total number of days ever absent from work with back trouble for the sample of Gatwick & HQ police officers (correlation coefficient 0.1868), but not for Traffic police. There were no other significant positive correlations.

Body Mass Index

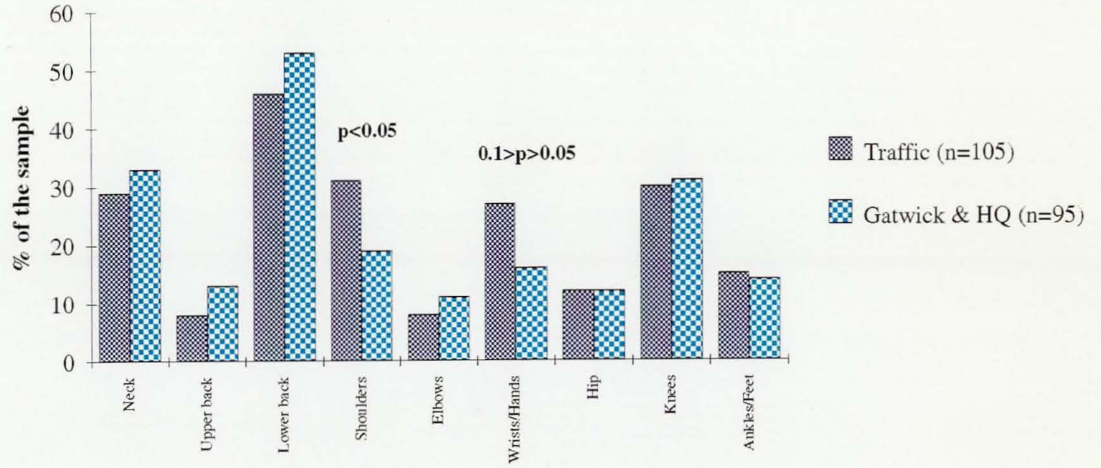
Body mass index was calculated by weight in kilograms, divided by the square of height in metres. The results for the sample population are shown in Table 33.

Figure 17. The prevalence of musculoskeletal troubles in police officers (n=200).

Point prevalence (i.e. last 7 days)



Period prevalence (i.e. last 12 months)



Severity (i.e. preventing normal activity)

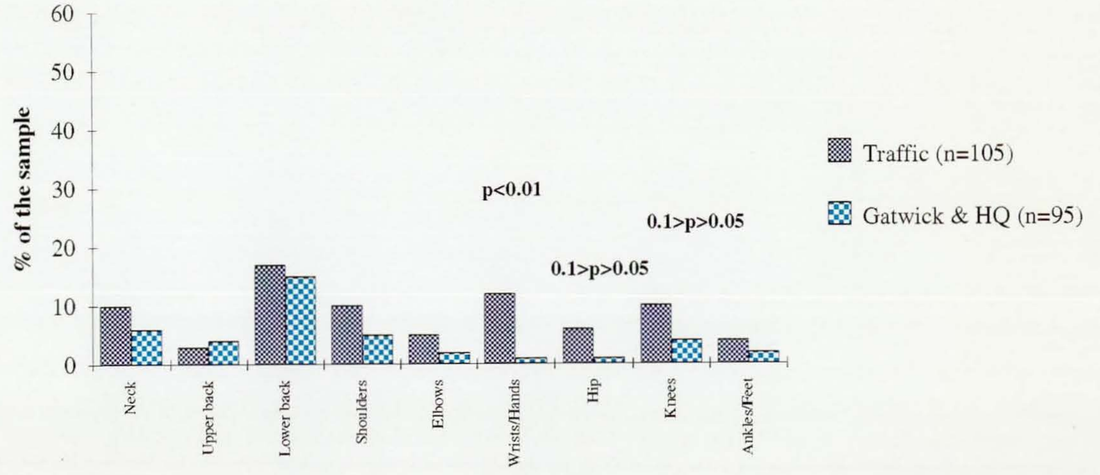


Table 33. Body mass index according to group.

Group	Mean (SD)	Range
Traffic (n=105)	24.97 (2.88) 2% underweight (under 20) 70% acceptable (20-25) 23% overweight (26-30) 5% seriously overweight (31-40)	19.47-37.37
Gatwick & HQ (n=95)	24.7 (2.82) 4% underweight (under 20) 68% acceptable (20-25) 25% overweight (26-30) 3% seriously overweight (31-40)	18.41-33.08

There was a positive correlation between body mass index and the total number of days ever absent from work ($p<0.0001$) and the number of days absent from work in the last 12 months ($p<0.05$) with low back trouble, but only for the sample of Gatwick Patrol & HQ. There were no other significant positive correlations.

6.5.2 Lifestyle

Smoking

The sample of police officers consisted of 33 smokers (17%). The number of cigarettes smoked by group is shown in Table 34.

Table 34. The number of cigarettes smoked a day by group.

Gender	Number of cigarettes per day Mean (SD), Range
Whole sample (n=33)	12.30 (6.82), 1-30
Traffic (n=12)	11.92 (5.96), 1-20
Gatwick & HQ (n=21)	12.52 (7.4), 1-30

There were no significant correlations found between the number of cigarettes smoked per day and low back, neck or shoulder trouble. Comparing smokers with non-smokers, there were no significant differences between the groups for both the sickness absence criteria and the prevalence and severity of musculoskeletal trouble.

Sport

The number of hours which ten 'risk sports' (i.e. high risk for neck and back pain, Porter and Porter 1990) were participated in regularly each week are shown in Table 35. The difference between the two groups for 'risk sports' was approaching significance (0.1>p>0.05), the number of hours being higher for Gatwick & HQ.

Table 35. The number of hours 'risk sports' (for neck and low back pain) were participated in each week by group.

Gender	**Hours of 'risk sports'** Mean (SD), Range
Whole sample (n=200)	2.54 (3.41), 0-19
Traffic (n=105)	2.12 (2.66), 0-11
Gatwick & HQ (n=95)	2.95 (3.95), 0-19

The significant positive correlations between the number of hours that 'risk sports' were participated and shoulder trouble are shown in Tables 36 and 37.

Table 36. Correlation coefficients (Spearman's rank) for 'risk sports' and sickness-absence criteria (drivers of all vehicles).

Criteria	**Whole sample** (n=200)	**Traffic Police** (n=105)	**Gatwick & HQ** (n=95)
Total length of time shoulder trouble suffered in the last 12 months.	.1469 *	.2333 *	.1104
Total length of time shoulder trouble has prevented normal activity in the last 12 months.	.1955 **	.1767 (a)	.3210 **

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

The control group (Gatwick & HQ) also showed significant positive correlations between 'risk sports' and the number of days absent from work with neck trouble in the last 12 months (p<0.05, correlation coefficient 0.2143), and the total length of time neck trouble had prevented normal activity in the last 12 months (p<0.05, correlation coefficient 0.2544). This was also true for car drivers only from this group as follows; the number of days absent from work with neck trouble in the last 12 months (p<0.05, correlation coefficient 0.2144) and the total length of time neck trouble has prevented normal activity ($p<0.05$, correlation coefficient 0.2472).

Table 37. Correlation coefficients (Spearman's rank) for 'risk sports' and sickness absence criteria (car drivers).

Car drivers only			
Criteria	**Whole sample** (n=171)	**Traffic Police** (n=80)	**Gatwick & HQ** (n=91)
Total length of time shoulder trouble suffered in the last 12 months.	.1158	.1581	.1093
Total length of time shoulder trouble has prevented normal activity in the last 12 months.	.2726 ***	.3024 **	.3219 **

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

6.5.3 Work Details

All of the sample population were employed by Sussex police Traffic Division or Gatwick and HQ Divisions. All of the police officers worked a basic 40 hour week and were on the OTOWA shift system described in Appendix 5. Most of the sample were satisfied with their job as follows:-

	Traffic	**Gatwick & HQ**
Satisfied	70%	64%
Partially satisfied	23%	27%
No feelings either way	3%	5%
Not satisfied	3%	3%
Would like a change	1%	1%

They travelled to work as follows:-

	Traffic	**Gatwick & HQ**
Walk	3%	1%
Cycle	18%	4%
Public transport e.g. bus	0%	0%
Drive themselves by car	62%	88%
Other	17%	6%

Details regarding the work journey for those who drove themselves to work by car are shown in Table 38 by sample group.

Table 38. Journey to work in distance and minutes taken .

	Traffic (n=105)		Gatwick & HQ (n=95)	
Journey to work	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
Journey length (miles)	9.42 (6.43)	1-30	15.48 (12.14)	1-90
Time taken (minutes)	20.35 (11.18)	3-45	27.56 (16.25	5-120

6.5.4 Vehicle Details

The range of main vehicles driven by the sample of 200 drivers was as follows:-

	Traffic (n=105)	**Gatwick & HQ** (n=95)
Supermini e.g. Ford Fiesta	3%	11%
Small family car e.g. Fiat Tipo	13%	36%
Large family car e.g. Vauxhall Cavalier	57%	37%
Executive car e.g. BMW 520i	1%	9%
Luxury car e.g. Mercedes-Benz 500SE	1%	1%
Coupe/Sports car Porsche 968	0%	1%
MPV e.g. Renault Espace RT	0%	1%
Off-roader e.g. Land Rover Discovery	1%	0%
Motorbike	20%	4%
Van-Light Commercial	4%	0%
Van -Heavy Commercial	0%	0%
HGV	0%	0%
Bus	0%	0%
Other	0%	0%

N.B. The main vehicle for Traffic Division was always a police vehicle.

The years in which the cars only were registered were as follows:-

	Traffic (n=80)	Gatwick & HQ (n=91)		Traffic (n=80)	Gatwick & HQ (n=91)
1993	15%	1%	1984	0%	3%
1992	31%	9%	1983	0%	5%
1991	20%	8%	1982	0%	1%
1990	19%	11%	1981	0%	1%
1989	9%	19%	1980	0%	0%
1988	4%	11%	1979	0%	0%
1987	0%	11%	1978	0%	1%
1986	2%	10%	1977	0%	0%
1985	0%	8%	1976 and older	0%	1%

N.B. The cars driven by Traffic were always police vehicles.

Vehicle Adjustments

Adjustable features on the cars in the sample were as follows:-

Traffic Division (n=80)

69% had seat height adjustment

56% had cushion tilt adjustment

96% had backrest angle adjustment

61% had lumbar support adjustment

65 % had steering wheel adjustment

Considering Traffic Division cars (police vehicles), 1% had an automatic gearbox, 0% had a sunroof and 0% had cruise control. Of these drivers 8% reported that there was not enough headroom in their vehicle, 9% reported that their pedals were in an uncomfortable position and 6% reported that their steering wheel was in an uncomfortable position.

Gatwick and HQ Divisions (n=91)

2% had seat height adjustment

44% had cushion tilt adjustment

97 % had backrest angle adjustment

37% had lumbar support adjustment

43% had steering wheel adjustment

Considering Gatwick and HQ Division cars which were all privately owned, 11% had an automatic gearbox, 77% had a sunroof and 7% had cruise control. Of these drivers, 6% reported that there was not enough headroom in their vehicle, 2% reported that their pedals were in an uncomfortable position and 1% reported that their steering wheel was in an uncomfortable position.

6.5.5 Exposure to Driving

Once again with regard to reported prevalence, sickness absence and discomfort, the results from this section onwards are concerned with car drivers only from both sample groups. The numbers of drivers of other types of vehicle were generally too small for separate analysis. Consideration of the whole sample of Traffic and Gatwick & Headquarters (HQ) Divisions (including motorcyclists) is given in Gyi and Porter (1994).

Discomfort

Considering the sample of car drivers, the frequency of discomfort when driving was reported as follows:-

	Traffic (n=80)	**Gatwick & HQ** (n=91)
Always	5%	0%
Often	15%	3%
Sometimes e.g. long journeys	26%	17%
Rarely	16%	15%
Never	38%	65%

62% of Traffic police and 35% of Gatwick and HQ car drivers experienced discomfort. The body areas in which discomfort was experienced are shown in Figure 18 by group and under what circumstances are shown in Figure 19.

Annual mileage

The mileage over the last 12 months is shown by age group for Traffic and Gatwick HQ car drivers separately, with the significant differences between the two divisions (Table 39).

Figure 18. Body areas in which car drivers experienced discomfort (n=171).

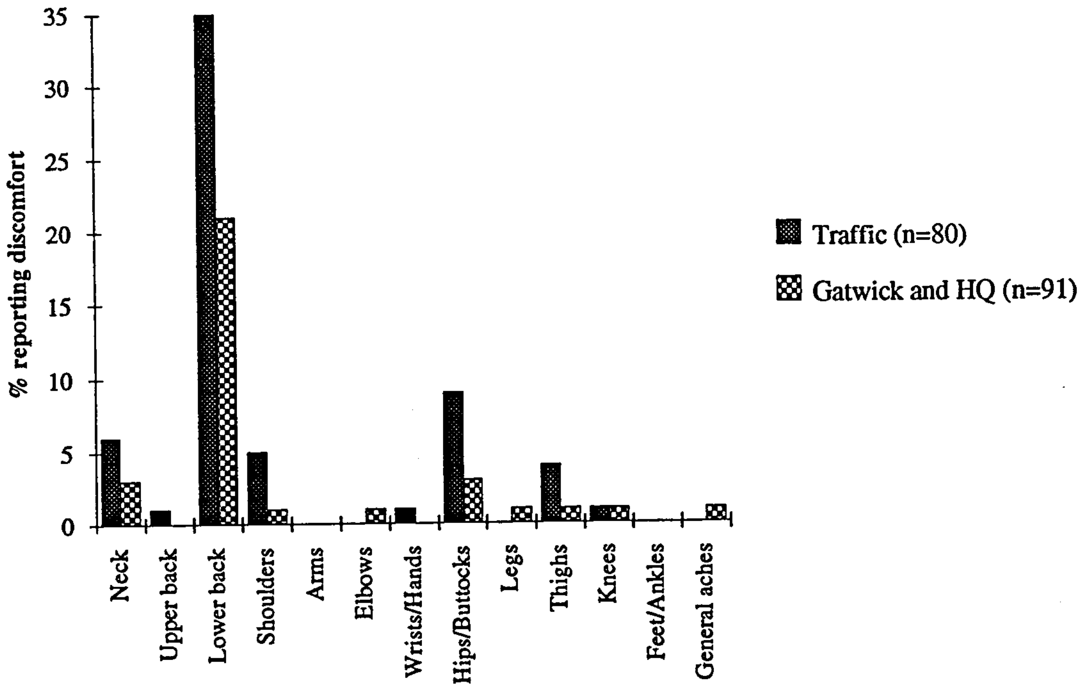


Figure 19. Circumstances under which discomfort occurs for car drivers (n=171).

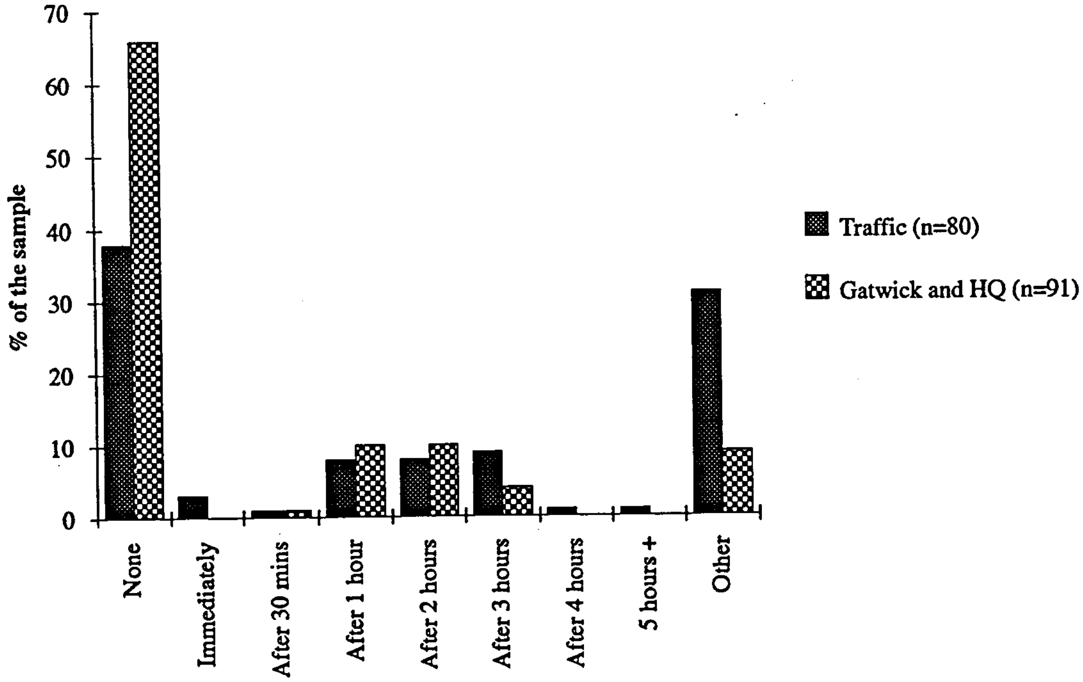


Table 39. Annual mileage of car drivers by age group and division with the significant differences.

Age group	Traffic (miles) Mean (SD)	Gatwick & HQ (miles) Mean (SD)	Significance of F
Whole sample	26,791 (9,019) n=80	12,610 (4,822) n=91	***
20-29	27,250 (9,110) n=16	14,065 (4,927) n=23	***
30-39	28,768 (11,628) n=29	12,046 (5,243) n=32	***
40-49	25,354 (5,765) n=31	12,796 (3,798) n=27	***
50-59	21,750 (6,238) n=4	10,344 (5,314) n=9	*

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Considering the whole sample of car drivers together there was a significant positive correlation ($p<0.05$) between annual mileage and the length of time low back trouble was suffered in the last 12 months (correlation coefficient 0.1712). There was also a positive correlation approaching significance between annual mileage and the total number of days absent with neck trouble in the last 12 months (correlation coefficient 0.1342).

The whole sample of car drivers was then divided into three similarly sized groups according to their mileage over the last 12 months. Differences approaching significance were found between the groups for the number of days absent from work with low back trouble in the last 12 months with the high mileage group (more than 25,000 miles) having the greatest problems (Table 40). There were no significant differences for neck and shoulder trouble. Car drivers also reported more frequent discomfort with their vehicle with increasing annual mileage (Figure 20).

Figure 20. Reported discomfort of car drivers according to number of miles driven over the last 12 months (n=171).

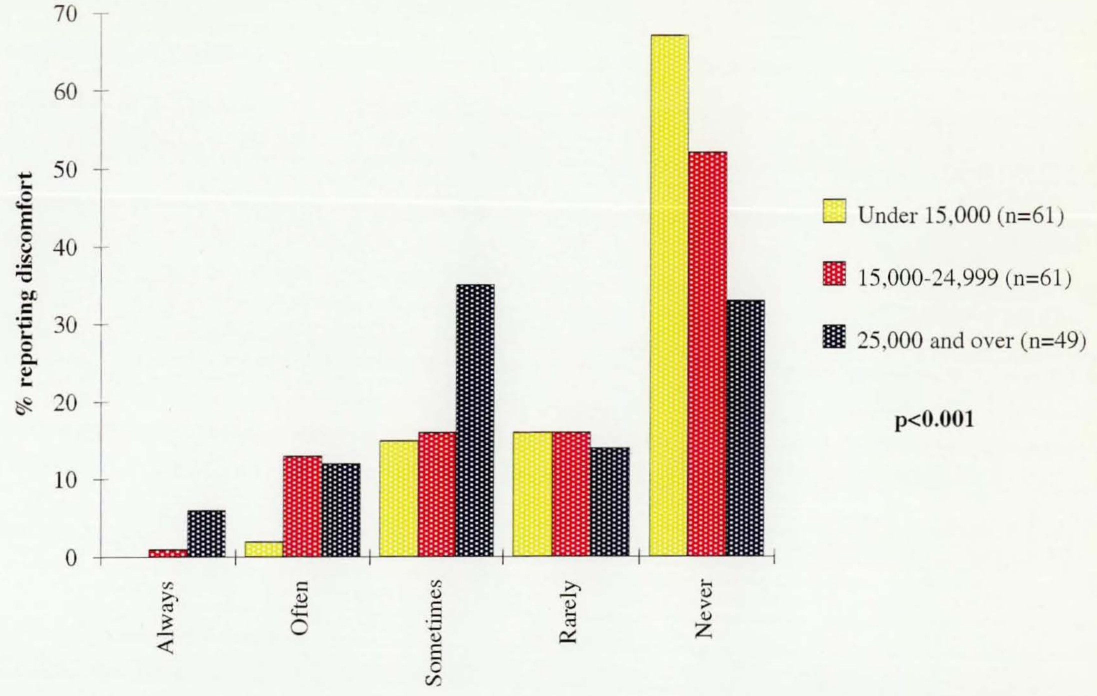


Figure 21. Number of days low back trouble experienced in the last 12 months according to driving a car (Traffic) compared with other work tasks.

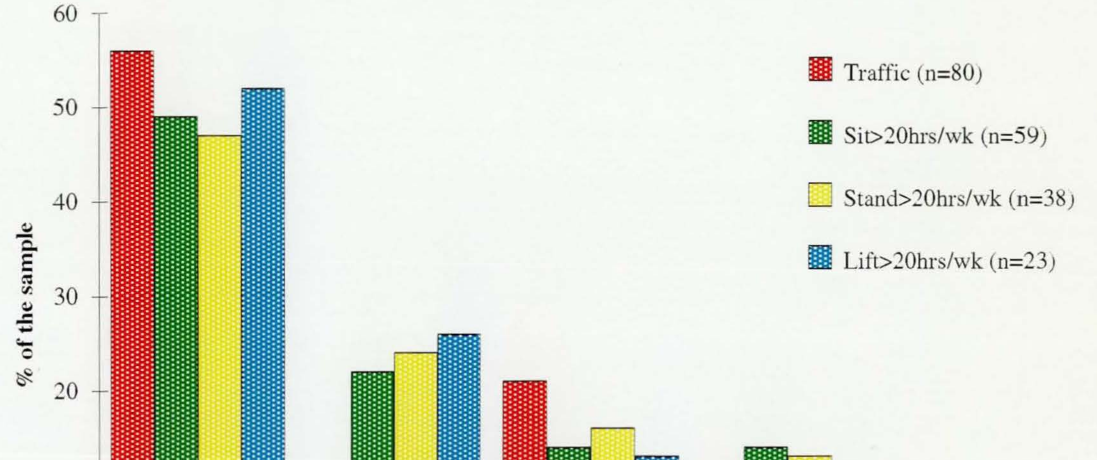


Table 40. Means and significance levels for sickness absence variables according to annual mileage group.

Car drivers (n=171)				
Criteria	**Group 1** Under 15,000 miles. Mean (n=61)	**Group 2** 15,000-24,999 miles. Mean (n=61)	**Group 3** 25,000 miles and over. Mean (n=49)	Significance
Total number of days absent with **low back trouble** in the last 12 months.	.67	.43	2.84	(a)
Total number of days absent with **neck trouble** in the last 12 months.	.48	.67	1.88	NS
Total number of days absent with **shoulder trouble** in the last 12 months.	.00	.36	1.00	NS

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Traffic Division compared with Gatwick & HQ car drivers

These two groups were originally selected for their different levels of exposure to car driving. Low back trouble for more than 8 days in the last 12 months was experienced by 38% of Traffic police compared with 26% of Gatwick & HQ police ($p<0.01$). When all police officers who had suffered neck, shoulder and low back accidents were removed from this sample, it was still found that 34% of Traffic police compared with 14% of Gatwick & HQ experienced low back trouble for more than 8 days during the last 12 months ($0.1>p>0.05$).

The period prevalence and severity of wrist / hand trouble was higher with car drivers from Traffic police compared to Gatwick & HQ (prevalence $p<0.05$, severity $p<0.01$). Traffic police also reported more frequent discomfort with their cars than Gatwick & HQ police ($p<0.001$).

Journey to work in terms of distance and time

Table 41 shows that the length of the journey driven to work by car in terms of its distance and the number of minutes duration, positively correlated with the length of time the individual had suffered low back trouble in the last 12 months, but only for the control group (Gatwick & HQ).

Table 41. Correlation coefficients (Spearman's rank) for journey to work by time (number of minutes) and distance for sickness-absence criteria.

Car drivers			
Criteria	**Whole sample** (n=171)	**Traffic** (n=80)	**Gatwick & HQ** (n=91)
Total length of time low back trouble experienced in the last 12 months.	.1041 (time) .0787 (distance)	.0192 (time) -.0638 (distance)	.2225 * (time) .2178 * (distance)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

6.5.6 Work Factors

Driving versus sitting

When the group of officers from Gatwick & HQ who sat for more than 20 hours a week as part of their job were compared to Traffic police car drivers, there was a significant difference between the groups for the total number of days low back trouble was experienced in the last 12 months (p<0.05), the number of days being higher for Traffic police car drivers (Figure 21). For example 7% of Traffic police car drivers compared with 1% of Gatwick and HQ sitters experienced low back trouble everyday in the last 12 months. There were no other significant differences between the groups.

Driving versus standing

If the group from Gatwick & HQ who stood for more than 20 hours a week as part of their job were compared to Traffic police car drivers, there was a significant difference between the groups for the total number of days low back trouble was experienced in the last 12 months (p<0.05). For example, 41% of Traffic police car drivers compared with 30% of Gatwick and HQ 'standers' experienced low back trouble for more than eight days in the last 12 months (Figure 21).

Driving versus lifting

The group of car drivers from Traffic, reported significantly higher levels of sickness absence than those officers at Gatwick & HQ who lifted 5 kg or more, often (more than 10 times an hour) as shown in Table 42.

Table 42. Means, standard deviations and the significance levels for lifting / driving (Traffic car drivers) and sickness absence criteria.

Criteria	**Traffic** Driving main task at work Mean (SD) (n=80)	**Gatwick & HQ** Lift 5kg or more (>10 times/hour) at work Mean (SD) (n=23)	**Significance**
The number of occasions ever absent from work with **low back trouble.**	.51 (1.2)	.17 (.39)	*
Total number of days ever absent from work with **low back trouble.**	11.21 (34.63)	2.96 (7.36)	*
The number of occasions ever absent from work with **neck trouble.**	.34 (1.04)	.22 (.42)	NS
Total number of days ever absent from work with **neck trouble.**	8.26 (25.32)	1.78 (4.16)	*

For these same groups there was also a difference approaching significance for the total number of days low back trouble was experienced in the last 12 months ($0.1>p>0.05$). It wasn't clear to see where the difference lay (Figure 21), but it appears that more Traffic Division car drivers have experienced low back trouble in the last 12 months for more than 8 days (38% compared with 22%).

Job satisfaction

Once again there were no significant correlations between job satisfaction and any of the sickness absence or prevalence and severity criteria.

6.5.7 Multiple Regression Analysis

As with the general public survey, it was decided to use the technique of multiple regression analysis in order to clarify the relative importance of different variables in contributing to sickness absence with low back trouble (the dependent variable) in the samples of police officers.

The sample of Traffic Division car drivers was considered first. Once again the variables concerned with personal details, sports activity, work activity, having a back accident and exposure to driving were entered into the multiple regression procedure. Regression diagnostics (standardised residuals, standardised scatter plots, leverage, normal probability plots and Cook's distance) once again identified subjects who were possible outliers or points of influence, but the author was satisfied that these were genuine values and should remain in the sample. As with the general public survey attempts to normalise the data were impossible as 29% of Traffic police car drivers had ever had sickness absence due to low back trouble (2-250 days), leaving 71% who had no days. Again a statistical approach based on adjusted r-squared was used to decide the 'best fit' to the model. The best model explained 10.7% of the variance, with the variables 'having a back accident' and 'hours driven as part of work' (Table 43). The low VIF values (1.001 and 1.001) indicated no multicollinearity, but model misspecification suggested caution in basing conclusions on the values of the correlation coefficients.

Table 43. Variables entered into the multiple regression equation for 'best fit' of the model to the sample of Traffic Division car drivers. The dependent variable is sickness absence ever due to low back trouble.

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
Back accident	.0894	.0045	13.6199	4.6514	1.001	
Hours driven at work	.1072	.1043	-.0441	.0276	1.001	15.0201

Considering the sample of car drivers from Gatwick and HQ, the same problems of model misspecification were encountered with attempts to build the model of 'best fit' using the statistical approach. However the best model accounted for 21.2% of the variance, with the variables 'having a back accident' and 'weight' having a highly significant effect (Table 44). Once again low VIF values (1.045 and 1.045) indicated multicollinearity was not a problem.

Table 44. Variables entered into the multiple regression equation for 'best fit' of the model to the sample of Gatwick & HQ car drivers. The dependent variable is sickness absence ever due to low back trouble.

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
Back accident	.1214	.0004	8.9075	2.8835	1.045	
Weight	.2116	.0012	.6489	.1940	1.045	-53.1845

The multiple regression model identified from the sample of those who drove as part of their job in the general public survey (Chapter 5.4.9), was then tested with the sample of car drivers from Traffic Division. As mentioned previously subjects who were possible outliers or points of influence were identified, but no errors were found in the data therefore these subjects remained in the sample. Fitting the variables 'hours driven as part of work', 'having a back accident' and the 'number of cigarettes smoked a day' to the model, this time explained only 7.8% of the variance and only the effect of 'having a back accident' was significant (Table 45). The low VIF values (1.011,1.008 and 1.018) indicated that there were no problems with multicollinearity but the fact that the effects of these variables on adjusted r-squared (statistical approach) were not significant suggested that this model did not adequately describe this data set.

Table 45. The 'best fit' model from the general public survey tested with Traffic Division car drivers. Sickness absence ever due to low back trouble is the dependent variable.

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
Hours driven at work	-.00004	.3212	-.5747	.5722	1.011	
Back accident	.0894	.0043	13.8756	4.7421	1.008	
Number of cigarettes smoked	.0777	.8895	-.1262	.9050	1.018	12.88

As with the general public survey a sample with a more normal distribution of the variable sickness absence due to low back trouble was required in order to build a correctly specified model. To achieve this, subjects from the whole sample of police officers (n=200), with sickness absence ever due to low back trouble were examined. This sample of 57 subjects consisted of 28 officers from Traffic Division and 29 officers from Gatwick and HQ. Transformation of the variable 'sickness absence ever with low back trouble' into logarithms improved the 'fit' of the data to the normal distribution curve. However using the statistical approach based on adjusted r-squared, it was not possible to build a multiple regression equation. The best model explained only 1% of the variance.

6.6 Discussion

The discussion will once again focus on the main findings relevant to car seat design and will be discussed in the light of the findings from the general public survey. Generally, the findings from the police survey supported those of the general public survey and therefore, if the points for discussion from the literature are the same they are only briefly mentioned.

The sample consisted of mainly males working for Sussex Constabulary in either Traffic (the study group) or Gatwick & HQ (the control group) Divisions, chosen because of their different exposures to driving at work. The age group was slightly lower than the general public survey. It is difficult to assess whether the sample is representative of a sample of police officers in Great Britain in terms of age and body build, for example. However, perhaps it can be assumed that as there will be similarities with other police forces (for example education, financial situation and duties), comparisons in terms of exposure to driving may have implications for the police generally.

The lifetime prevalence of low back trouble was 65% for Traffic Division and 66% for Gatwick & HQ and was higher than in the general public survey (56% of men), but more similar to the figures quoted by Walsh et al (1989) of 64% of men and Biering-Sorensen (1983) of 68% of men. All of the police were in employment at the time of the interview but this was not certain in the other studies.

6.6.1 Exposure to Driving

It was noted that there was a trend (not significant) for a slightly higher point prevalence and period prevalence of low back trouble in Gatwick and HQ police officers when the whole sample was considered (Figure 17). The prevalence figures became more similar when car drivers only from both samples were considered. It therefore must be concluded that both samples of car drivers had a similar point prevalence (19% for Traffic and 20% for Gatwick and HQ) and period prevalence (45% for Traffic and 49% of Gatwick and HQ) of low back trouble.

However, looking in more detail at the sickness absence data, the results from this study still indicate that car driving does have a potential effect on sickness absence due to low back trouble, but the results were not so clear as those from the general public survey. A higher number of Traffic police car drivers (38% compared with 26%) experienced low back trouble for more than 8 days during the last 12 months. The police in general have a high incidence of accidents and assaults which could have had a confounding effect on low back trouble. When car drivers only from both groups who had not had any neck, shoulder or low back accidents were compared, the Traffic Division car drivers still experienced more low back trouble in the last 12 months (34% of Traffic compared with 14% of Gatwick & HQ had more than 8 days). This was in spite of Traffic Division being a popular division to work, such that it was unlikely that the levels of back trouble experienced were increased by low levels of motivation.

Dividing the sample of car drivers according to their annual mileage also revealed a higher number of days absent with low back trouble in the last 12 months for the high mileage (25,000 miles and over) drivers; 2.84 days compared with 0.67 days for lower mileage drivers (15,000 miles and under). The differences between the mileage groups were not as strong as for the general public data (only approaching significance), perhaps due to the fact that only 15% of the sample from the police drove under 10,000 miles over the last 12 months and 0% of the sample drove less than 5,000 miles (i.e. were low mileage drivers).

The longer the car journey to work in terms of distance and time, the greater the length of time low back trouble was experienced in the last 12 months, but only for the control group (Gatwick & HQ). A reason for this could be that Gatwick & HQ had considerably longer journeys to work (15.48 miles, SD 12.14 compared with 9.42 miles, SD 6.43). A more likely reason is that the journey to work for the control group was a major part of their annual mileage whereas this was not the case for Traffic police.

Car drivers from the Traffic police also had a significantly higher period prevalence, point prevalence and severity of wrist / hand trouble than Gatwick & HQ. This agrees with the general public survey, where there was a relationship between wrist / hand trouble and the number of hours driven as part of work. The particular effect of increased exposure to driving resulting in more frequent reporting of wrist / hand pain has not been documented in the literature.

In the multiple regression analysis, the variable 'hours driven as part of work' was again selected along with the variable 'having a back accident' as being of significant importance in explaining the number of days ever absent from work with low back trouble for Traffic Division car drivers. This was not so for the Gatwick and HQ data, although 'having a back accident' was selected as being of importance. As with the general public survey there was some model misspecification for both data sets, but it was judged that the variables selected were of value in explaining the number of days ever absent with low back trouble.

Again the results of this study support the findings of other authors that car driving is a risk factor for low back trouble (Frymoyer et al, 1983; Damkot et al, 1984; Pietri et al, 1992 and Walsh et al, 1989). It is thought that the results comparing the two groups of police officers were not as convincing as the general public survey because all police officers from both groups drove more than 10,000 miles a year, the majority (61%)

driving more than 15,000 miles year. Also, they were all employed in an 'active' job which was known to be subject to stress (Alexander et al 1991) and therefore as a profession perhaps they were at high risk from developing musculoskeletal troubles. In support of this reasoning, Richards and Fell (1985) found that there was a higher incidence of health problems (not specified) in the police than other occupations. Also, Hurrel et al (1984) found that the numbers and types of health disorders reported by police officers over a six month period was similar to those found in the general public over a twelve month period.

Discomfort was reported in at least one body area by 62% of the study group (Traffic) and 35% of the control group (Gatwick & HQ). As with the general public survey, there was an increased frequency of reported discomfort with higher annual mileage. In Figure 20 it can be seen that 18% of high mileage drivers (25,000 miles and over), 'always' or 'often' had discomfort with their car compared with only 2% of lower mileage drivers (under 15,000 miles).

Figure 18 clearly shows that the most frequently reported body area which car drivers experience discomfort was the low back (35% of Traffic and 21% of Gatwick & HQ), hips / buttocks (9% of Traffic and 3% of Gatwick & HQ) and neck (6% of Traffic and 3% of Gatwick & HQ). The mean percentage reporting low back trouble for the whole sample of the police (28%) is comparable with both the general public survey and the study carried out by Porter et al (1992).

6.6.2 Comparison of Driving with other Working Postures

Traffic police car drivers were compared with three separate groups from Gatwick & HQ; those whose job involved sitting (not driving) for a large part of the day, a group whose job involved standing for a large part of the day and finally a group whose job involved lifting for a large part of the day. Once again the results indicated that car driving as part of work should be taken seriously with regard to low back trouble. Considering the group of car drivers from Traffic, 38% compared with 29% of Gatwick & HQ 'sitters', 29% of Gatwick & HQ 'standers' and 22% of Gatwick & HQ 'lifters', experienced low back trouble for more than 8 days in the last 12 months (Figure 21). The differences between the groups were significant for the 'sitters' and 'standers' ($p<0.05$). Interestingly, in contrast to the above it seems that the 'sitting', 'standing' and 'lifting' groups experienced more low back trouble lasting in the range of 1-7 days than the driving group (Figure 21). It could be that the low back trouble experienced by the driving group was aggravated by the high exposure to driving, such that it carried on for longer.

Surprisingly, car drivers from Traffic also had a greater number of occasions and days ever absent from work with low back trouble than the 'lifting group', for example 11.21 days compared with 2.96 days. The fact that police officers from Gatwick & HQ who did frequent lifting, had less sickness absence due to low back trouble than the car drivers from Traffic police, could be explained by the fact that Traffic police do a certain amount of lifting when necessary as part of their job anyway, as well as having a high exposure to driving. For example, they assist scenes of accidents and lift objects such as Traffic cones and signs out of the car boot. However, this may not be reported as 'lifting, often' as asked by the questionnaire (i.e. lifting 5 kg an hour, 10 times an hour). Many of the studies reviewed also recognise that lifting is associated with an increased risk of low back pain, for example Frymoyer et al (1983), Walsh et al (1989) and Pietri et al (1992). Although Kelsey (1975), concluded that there was no evidence of an increased risk of herniated lumbar discs in males who carried out lifting as part of their job.

6.6.3 Personal Details

Having shown an association between driving and low back trouble once again, it was important to look more closely at the other factors which may have an influence.

The relationship between age and low back trouble was approaching significance, but only for the sample of Gatwick & HQ. However, there was no significant relationship between age and annual mileage. This indicates that age does not have a major effect on the relationship between driving and low back trouble which agrees with the general public survey. Other authors as discussed previously, for example Reisbord and Greenland (1985) and Burton et al (1989), also failed to find a clear relationship between age and low back trouble. There were no relationships between age and the prevalence of musculoskeletal troubles in the large joints, unlike the general public survey. This could be due to the fact that all of the police were 'fit' for work, whereas the general public survey included people 'unfit' for work. The age range was also greater with the general public.

As with the general public survey, the body mass index was found to be positively correlated with the number of days ever absent from work with low back trouble, but only for Gatwick & HQ. However, body mass did not show a significant relationship with exposure to driving and therefore, was unlikely to be a main reason for low back trouble in high mileage drivers. The variable 'weight' (from which body mass was calculated), was selected by the multiple regression analysis along with 'having a back accident', as being significantly important in predicting the number of days ever absent from work with low back trouble for the sample of car drivers from Gatwick and HQ. Despite the data not fitting all the assumptions for the test, these two variables accounted for 21% of the variance and are therefore together likely to be of importance for this data set. The 'weight' of Gatwick & HQ police officers was not significantly different from Traffic Division police officers, neither was there a significant correlation between weight and days ever absent with low back trouble for this group. The reason for the selection of the variable 'weight' cannot be explained .

The variable 'having a back accident', i.e. an acute back injury, was selected by multiple regression analysis as being of significant importance in explaining the number of days absent from work with low back trouble for both the sample of car drivers at Gatwick & HQ and the sample of Traffic Division car drivers. This is not surprising as it was found that 33 % of Traffic Division car drivers and 30% of Gatwick & HQ car drivers reported 'having a back accident'. It is therefore highly likely that having had a previous back accident is of importance in predicting the incidence of low back trouble. In support of this, Biering-Sorensen (1983) found that previous back trauma increased the risk of low back pain occurring in the next 12 months, particularly if it was recent and frequent and Riihimaki et al (1989) found that reported back accidents were strongly associated with the prevalence (12 months) of sciatic pain among machine operators, carpenters and office workers.

As with the general public survey, no significant correlations were found between cigarette smoking and low back trouble. However, unlike the drivers (as part of work) from the general public survey, the 'number of cigarettes smoked a day' was not selected as a significant variable in explaining low back trouble. There were also no differences between smokers and non-smokers for sickness absence and prevalence measures, whereas in the general public survey, smokers were absent from work more often with neck trouble. A reason for these differences could be that a slightly smaller percentage of police officers smoked than in the general public survey (17% compared with 24%), and they smoked a lower mean number of cigarettes (12.3 compared with 14.5). Some authors reported links between smoking and low back trouble (Frymoyer et al, 1983; Waddell, 1987; Biering-Sorensen et al, 1989; Frymoyer and Cats-Baril, 1991) and Kelsey et al (1984) found an increased risk of acute herniated lumbar disc, but this was not the case with this sample of police officers.

The number of hours ten 'risk sports' were participated in was significantly correlated with neck sickness absence, but only for the sample of Gatwick & HQ. However, both groups had a significant correlation between 'risk sports' and the number of days that shoulder trouble prevented normal activity. Gatwick & HQ participated in slightly more hours of 'risk sports' than Traffic Division ($0.1>p>0.05$). Unlike the general public survey no relationships were found between 'risk sports' and any of the low back trouble measures. This was despite the police actually taking part in more 'risk sports' than the general public (mean 2.54 hours SD 3.41, compared with 1.12 hours SD 2.22). The lack of a relationship could be as a result of the sample of police all being generally 'active' and fit for work. The work of Burton et al (1989) found that adult sports participation increased the risk of low back trouble, concluding that sports related injury in adult life reduced back mobility, increasing the risk of low back trouble. They also found evidence that early physical fitness enhanced back mobility and health. Finally, the number of hours these sports were participated in did not correlate with exposure to driving and therefore the effect of participation in 'risk sports' for this sample was likely to be minimal.

As with the general public survey, there were no significant relationships between job satisfaction and any of the sickness absence or prevalence measures. Most of the sample were generally satisfied with their job with only 1% of both Traffic and Gatwick & HQ Divisions reporting that they 'would like a change'. Once again, as detailed questionnaires regarding motivation, mood, stress etc. were not used confidence cannot be placed in this result.

The combined results of this survey and the general public survey are discussed in Chapter 7, together with the overall conclusions.

Chapter 7 General Discussion and Conclusions Regarding the General Public and Police Surveys

7.1 Introduction

This chapter links the results of the general public and police surveys presented in detail in Chapters 5 and 6. The main findings are discussed in the light of the literature with the implications for the general public, the police, employers and car manufacturers. The limitations / weaknesses of the surveys are then discussed. Future work is summarised along with the results of Part II in Chapter 14.

7.2 Discussion of the Main Findings of the General Public and Police Surveys

The results of both the general public and the police surveys clearly show that exposure to car driving in terms of both distance and hours driven, has a significant effect on reported low back trouble. Subjects in the general public survey who drove for more than 20 hours a week as part of their job, reported a mean number of days ever absent with low back trouble six times higher, than those who drove less than 10 hours a week as part of their job (51.4 days, SD 192.9 compared with 8.1 days, SD 34.2). In the police survey, 38% of Traffic police car drivers compared with 26% of Gatwick & HQ experienced low back trouble during the last 12 months. Removing the confounding effect of accidents (neck, shoulder and low back) this difference was even greater (34% of Traffic compared with 14% of Gatwick & HQ). Further evidence was provided by the multiple regression analysis, which identified the 'number of hours driven as part of work' as being important in explaining the number of days ever absent from work with low back trouble, for both the sample who drove as part of their job from the British public and the police.

Exposure to driving cars also had a significant effect on the reported period prevalence, point prevalence and severity of wrist / hand trouble. This was confirmed by both surveys although has not been documented in the literature.

Although specific comparisons with other studies are difficult because of the different study designs and means of collecting the data, broadly speaking these results add to the work of authors such as Kelsey and Hardy (1975), Walsh et al (1989), Pietri et al (1992) and Porter et al (1992) in linking car driving with low back trouble. As already reported the risks were noted to be of similar exposures i.e. driving for more than half the working day (Kelsey and Hardy, 1975), more than 4 hours a day (Walsh et al, 1989) and more than 20 hours a week (Pietri et al, 1992). This could be said to be the categories set for convenience, but Riihimaki et al (1989) used categories for annual mileage lower than the professional driver i.e. '<5,000 km', '5,000-15,000 km' and >15,000 km' and found that annual car driving was not a risk factor for the occurrence of sciatic pain, lumbago or other low back pain. An annual mileage of 15,000 km is approximately 10,000 miles / year or 200 miles / week, which is probably less than 20 hours driving a week. Further study is needed regarding the effect of different exposures to driving.

Although it cannot be claimed that the odds ratios calculated from the general public survey are truly predictive, they were comparable to the results of the above studies, such that it can be suggested that the odds for experiencing low back trouble are about 2-3 times as high for individuals who have a job which involves driving for more than 20 hours a week. As well as the personal costs to the employee, the recognised implications of the above for the employer are the hidden costs incurred in terms of days lost due to sickness absence such as loss of productivity and replacement training (Spengler et al, 1986).

The results of both surveys showed that there was a significantly higher frequency of reported discomfort as the annual mileage for car drivers increased. In the general public survey, discomfort was reported in at least one body area by 54% of car drivers, and in the sample of car drivers from Traffic police, 62% reported some discomfort. Driving for long periods means that the adoption of a good posture with efficient movement patterns is essential to delay the onset of discomfort and to help avoid possible health problems. Grandjean (1984) went further by supporting the view that postural strain led to an increased risk of inflammation of the joints, degenerative diseases and disc problems. In fact, the work of Kelsey and Hardy (1975) found that driving was a risk factor for acute herniated lumbar disc in subjects who spent half their time in a driving job (relative risk 2.75 for the matched sample). Car seat comfort was also one of the factors associated with the prevalence of low back trouble in the study by Pietri et al (1992).

The most frequently reported area for discomfort was consistently the low back (25% in Porter et al 1992, 26% in the general public survey and 28% in the police survey). The other most frequently reported area was the neck (10% in Porter et al 1992, 8% in the general public survey and 5% in the police survey). Traffic police car drivers also reported a high frequency (9%) of hip / buttock discomfort which could be a result of the pressure during long periods of sitting in a car, especially if the seat was in poor condition. The vulnerability of the low back in particular suggests a strong need for a comfortable car seat with a highly adjustable driving workstation in order to obtain the optimum driving position. Keegan (1953) felt that the most important requirement of a good seat was the placement of a support over the lower lumbar region in order to protect the vulnerable lumbar discs. Porter and Norris (1987) recommended a lumbar support with height adjustment as well as in / out adjustment.

Drivers from the general public survey whose car had no adjustable lumbar support, adjustable steering wheel, or automatic gearbox reported more sickness absence than drivers of cars with these features fitted. For example, drivers with no adjustable steering wheel had significantly more days absent with neck trouble in the last 12 months (0.47 days, SD 3.81 compared with 0.03 days, SD 0.21). Similarly drivers who reported problems with their driving position, for example poor positioning of the steering wheel suffered more frequent discomfort with their car (70% compared with 38% reported discomfort 'always', 'often' or 'sometimes'). These results are very similar to those found by Porter et al (1992) in their study of 1000 car drivers, where increasing discomfort was significantly associated with drivers of cars with no seat height, tilt or lumbar support adjustments. Pietri et al (1992) also found that the absence of a lumbar support was related to back pain symptoms and they concluded that lumbar supports and the ability to incline the seat were important prevention strategies. It seems that drivers of cars with the most adjustable driving packages benefit in terms of both reduced sickness absence and reduced discomfort. This is supported by the work of Akerblom (1948), cited by Keegan (1953), who felt that the ability to change posture was essential for comfort in any seat. More attention should therefore be paid to the hidden costs incurred if this adjustability is not provided. It is the only way to ensure that a whole range of sizes of drivers can adopt a healthy posture in their car.

One of the more surprising findings from both surveys was that those who drove as part of their job reported more sickness absence due to low back trouble than those whose jobs primarily involved sitting (not driving) or standing tasks. This finding is supported by the work of Kelsey and Hardy (1975) and Walsh et al (1989). This fact is worrying in that there is an abundance of literature, posters and other training material, warning of the dangers of sitting for long periods at computers and good lifting practise (as there should be), but nothing to inform the driver of the benefits of, for example, varying their posture frequently, or adjusting the car seat. The personal interest showed by employers, ergonomists and occupational health staff in the problems of discomfort experienced by the car driver and the consequent active involvement in 'treatment' by the individual may, as suggested by Waddell (1987), help a large number of them manage their problems of low back discomfort and driving. Also, Lacroix et al (1990) found that 94% of patients with a good understanding of their low back pain returned to work compared to only 33% of those with a poor understanding. They believed that patients will always develop their own naive theories of self diagnosis and treatment, which will in turn affect their prognosis.

Education of the general public, particularly the risk group of those who drive as part of their job such as the police (and their managers), should therefore be a priority to help reduce long term sickness absence due to low back trouble. The physical demands of driving should be taken seriously and not ignored. Training techniques need to be reviewed in the literature and then the potential benefits of such training need to be fully researched and evaluated. For example, Stubbs et al (1983b) investigated the effects of training nurses in patient handling techniques such as the 'Australian lift', but found that there was no evidence to suggest that the amount of training given (whether in the classroom or on the ward) was associated with the point prevalence of low back pain. Interestingly, in a study by Kuorinka et al (1994), thirty police officers (15 with a history of low back pain and 15 without) participated in the redesign of a police patrol car, with the aim of improving working conditions, whilst giving special consideration to reducing back disorders. The subjects were divided into three groups who met twice a week for three months. During these sessions teaching and discussion were carried out regarding automotive engineering, ergonomics, standardisation, regulations, the biomechanics of seating, back structure and other related topics. Their results found that all of the police officers were very motivated to improve the patrol car and made many suggestions which may decrease back pain in their working environment. Secondly, they found that over the course of the study, the focus of discussion moved away from back pain issues to design issues aimed at reducing low back pain. Police officers with a history of low back pain were particularly interested to stress the importance of posture during the tasks carried out whilst sitting in a police car. The results from this study need further investigation, but other studies similar to this are required in 'the field' in order to investigate the optimum way to communicate 'health care for the back' in situations such as driving. Finally, Bigos et al (1986) suggested time lost from work may be a good way of evaluating the effects of any preventive or therapeutic measures.

Many of the measures to prevent potential problems with drivers who drive as part of their job would not be under the control of the individual driver. This includes such measures as when to take breaks, time allowed for exercise regimes and the careful selection of their car with respect to postural criteria, as well as the consideration of purchase price, maintenance costs and depreciation. Therefore managers with the responsibility for purchasing vehicles for use by others need training in the importance of such measures. As awareness increases in the employers and the general public, hopefully manufacturers will be under increased pressure to offer suitably adjustable driving packages or risk a fall in their market share.

It could also be that these results are only the 'tip of the iceberg', with regard to cases of low back trouble in drivers, as all subjects interviewed were either working or ambulant walking around public places. Ohlsson et al (1994) also found that the Nordic Musculoskeletal Questionnaire (NMQ) gave an underestimation of musculoskeletal problems, when compared with the results of a detailed clinical examination. It is suggested that perhaps driving has emerged as a relatively recent risk factor for low back trouble because drivers have to endure greater exposure (miles and hours). It could also be that legislation and education with regard to lifting and VDU work, for example, has led to the improved design of other workstations and tasks.

7.2.1 Other Factors

As suggested by Rey (1979) symptoms of low back trouble are likely to be as a result of multiple relationships and influences. The fact that the maximum variance explained by any of the multiple regression analyses was only 25% and that the significant correlation coefficients themselves were generally low (for example 0.2000, $p<0.001$) were not surprising. Using the data from an extensive study of 31,200 employees at the Boeing Company carried out by Bigos et al (1986), it was reported by Battie and Bigos (1991) that out of 56 variables, only job satisfaction and emotional stress were significantly correlated with initial reports of low back pain. It was not reported if variables associated with exposure to driving were included in this analysis. In the light of this, it may be that some of the factors and influences associated with low back trouble may not have been measured in general public and police surveys due to the obvious practical issues. Some of the factors which were considered in these surveys are now discussed with the relevant literature.

It seems from the multiple regression analysis that having had a back accident is highly likely to be of significant importance in predicting the incidence of future low back trouble. It was selected as a significant factor in four data sets; car drivers as part of their job from the general public survey, the sample from the general public who have ever had sickness absence due to low back trouble, the sample of car drivers at Traffic Division and finally the sample of car drivers at Gatwick and HQ. This finding is supported by the work of Biering-Sorensen (1983), who found that previous back trauma increased the risk of future low back pain, and Riihimaki et al (1989), who found that reported back accidents were strongly associated with the 12 month prevalence of sciatic pain.

There were no statistically significant relationships between age and the prevalence of, or sickness absence with, low back trouble with the general public or police data, nor did exposure to driving correlate with age. However, when considering only the sample of subjects who had actually ever had days absent with low back trouble, 'age' was chosen as being predictive of the logarithm of sickness absence due to low back trouble along with 'having a job which involved sitting at work, often' (not driving) and 'having a back accident'. Only 12% of the variance was explained by these three variables, it can therefore be assumed that the effect of age on driving and low back trouble in the whole sample was minimal. This agrees with Reisbord and Greenland (1985), Waddell (1987) and Burton et al (1989) who reported that it was only in combination with other factors that age had some influence. Porter et al (1992) found that older drivers reported less discomfort with their car than younger drivers. The fact that their was a significant positive correlation between age and price of the car and that people driving cars with more adjustment features were older, suggested to the authors that the age effect was secondary to the price and so specification of the car. The prevalence of musculoskeletal troubles of the large joints such as the hips, ankles and elbows was found to be higher with increasing age in the sample of the general public but not the sample of police. This could be due to the greater age range in the former sample.

No significant correlations were found between cigarette smoking and low back trouble in either study. It was only in the multiple regression analysis for the sample of car drivers who drove as part of their job, in the general public survey, that the 'number of cigarettes smoked a day' was one of the three significant variables selected as being important in predicting the variable 'days ever absent with low back trouble'. It can be judged that along with 'hours driven at work' and 'having had a back accident' that 'the number of cigarettes smoked' was of slight importance in predicting low back trouble for this data set. A reason that the association was not found in Traffic police could be that a smaller percentage of these officers smoked, 11% compared with 20% of drivers of cars (as part of their job) from the general public survey. Frymoyer et al (1983), Waddell (1987), Biering-Sorensen et al (1989) and Frymoyer and Cats-Baril (1991) all support an association between cigarette smoking and driving. Battie and Bigos (1991) summarised the possible reasons for this association from the literature as being; decreased bone mineral content and osteoporosis; coughing and increased intervertebral disc pressure and changes in vertebral blood flow affecting disc metabolism. Also, only in the general public survey, when smokers were compared to non-smokers, smokers were absent from work with neck trouble on more occasions and for a greater number of days than non-smokers. It is not known why this should be the case.

The number of hours that ten 'risk sports' (i.e. high risk for neck and back pain, Porter and Porter 1990) were participated in showed a significant positive correlation with days ever absent with low back trouble but only for females in the general public survey. The only 'risk sports' that these females reported a higher number of hours of participation than males, were high intensity aerobics and horse riding, but there is no evidence to assume that participation in these sports leads to sickness absence with low back trouble. With the police, no relationships were found between 'risk sports' and any of the low back trouble measures, perhaps as a result of the sample of police all being generally 'active' and fit for work and that the sample only contained four females. Apart from this sample of females from the general public, the survey results disagree with the work of Burton et al (1989) who found that adult sports participation increased the risk of low back trouble, concluding that sports related injury in adult life reduced back mobility and increased the risk of low back trouble. However, Frymoyer et al (1983) concluded, from their questionnaire survey of men attending Family Health Care Unit, that sports activity had a minimal effect on low back pain.

Males from both the general public and police surveys revealed significant correlations between 'risk sports' and neck and shoulder problems preventing normal activity (work or leisure). This could be due to males participating in more hours of 'risks sports' for example rugby, squash, football and weights and the fact that participation in these demanding sports were likely to affected by injury Finally, the number of hours these sports were participated in did not show a significant correlation with exposure to driving in either sample and therefore the confounding due to 'risk sports' was likely to be minimal.

Gender differences were only investigated in the general public survey, where no significant differences were found between the sexes for any of the prevalence or sickness absence measures of low back trouble. The literature itself is contradictory, as Jonsson and Ydreborg (1985) found that males had a higher prevalence of low back trouble than females, whereas Reisbord and Greenland (1985) found that females had a lifetime prevalence of low back pain 4% higher than males. Reasons for gender differences were put forward by Reisbord and Greenland (1985) as being the fact that females have to cope with childbearing, they also have multiple role obligations, a different anatomy and show different responses to stress. With regard to other musculoskeletal troubles, it was found that females in the general public survey had a significantly higher point prevalence, period prevalence and severity of neck, shoulder, upper back and wrist / hand trouble than the males. This is supported in the literature by Jonsson and Ydreborg (1985) and Johansson (1994) who found that females had a significantly higher frequency of reported musculoskeletal troubles related to present work in the neck, shoulders and knees, although no reasons were put forward as to why this should be.

The effects of other work tasks which may have an influence on reported low back pain were investigated. Cautious interpretation is needed in cross-sectional studies such as this, as individuals who have low back pain may have changed to sedentary occupations. It was found by both surveys that driving a car for a large part of the day can be as detrimental as sitting and standing postures, with regard to reported low back trouble. Kelsey and Hardy (1975) found that the 'relative risk' for sitting whilst driving was nearly twice as high as that for sitting in a chair regardless of the type of chair. Surprisingly, Traffic police car drivers also had more occasions and days ever absent from work as part of their job than those police officers from Gatwick and HQ whose jobs involved a large amount of lifting. This could be explained by the fact that Traffic police do a certain amount of lifting when necessary as part of their job anyway. For example, they assist at the scene of an accident, but as explained previously this may not be reported to be 'lifting, often' as asked by the questionnaire (i.e. lifting 5 kg an hour, 10 times an hour). It could be that the combined effect of this lifting and driving may have accounted for the high sickness absence due to low back trouble in Traffic police. Many of the studies reviewed also recognise that lifting is associated with an increased risk of low back pain, for example Frymoyer et al (1983), Walsh et al (1989) and Pietri et al (1992). Kelsey (1975) however, concluded that there was no evidence of an increased risk of herniated lumbar discs in males who carried out lifting as part of their job. In this study comparing cases with controls (as explained in Chapter 2.2), broad categories for the lifting were used i.e. five categories ranging from 5-50 lbs for 'weight' and five categories ranging from once a day to 20 or more times a day for 'frequency'. She concludes that despite these rough indicators of lifting, if lifting at work was an important factor some association would have been found.

7.2.2 Limitations of the Questionnaire and Survey Design

Although this work added more detail to the picture of the association between driving and low back trouble, a limitation must be the fact that the two surveys were cross-sectional in design and therefore, as previously mentioned, the variables identified as being important cannot be assumed to be predictive. Prospective studies are more suited to yield valid information but the time required waiting for low back trouble to develop and the fact that a large sample size is usually needed adding to the cost, made this design not an option. Rey (1979), suggested that in order to be of importance the association should be strong, repeatedly observed, the underlying cause specific and the degree of exposure and time interval should relate to the effect. In an ideal world the author agrees with this statement, but due to the constraints of time and cost, it was not possible to design a study which met all these criteria. The results were confirmed by both surveys and supported by the work of other authors as discussed. Although generally the correlations were significant, they were low, but perhaps this is not surprising as explained in Section 7.2.1 given the nature of the research. Despite the latter, the author feels that this work is still of importance in its contribution to the growing body of research investigating the effect of driving on the prevalence / incidence of low back trouble.

The Nordic Musculoskeletal Questionnaire (NMQ) was found to be a useful tool to obtain prevalence and sickness absence data regarding musculoskeletal troubles. Its use saved time in designing and validating an entirely new questionnaire. Previous work, for example, Andersson et al (1987), Kuorinka et al (1987), Burdoff and Zondervan (1990) and Dickinson et al (1992) had found it sensitive enough to evaluate the distribution of musculoskeletal troubles in different work forces. More recently, it was found to be able to pick up the pattern of injuries between two similar workstations in a manufacturing plant (Deakin et al, 1994). They also found that it was robust enough to gain similar information when two slightly different forms of the questionnaire were administered by two different interviews.

Several of the recently published users of the NMQ have added their own questions to the main body of the questionnaire. These ideas were too late for consideration for inclusion in the general public and police surveys but may be useful for future studies. Bru et al (1994) investigated musculoskeletal troubles in 586 female hospital staff. In addition to the dichotomous scale (yes, no), a sub scale was added for assessment of the maximum intensity of the trouble over the last 12 months. The scale used was reported to be from Westgaard and Jansen (1992) and was as follows:-

0. No complaint.
1. Almost no complaints, only slight feelings of discomfort at breaks, when not concentrating on the work task.
2. Slight, but noticeable complaints when performing the work tasks. However, these are of sufficiently low intensity not to interfere with performance at work.
3. Relatively strong complaints during work, making it necessary to maintain a conscious effort in order to carry out the work task. It is necessary at times to have breaks, owing to the discomfort experienced. The feelings of discomfort are relieved following such breaks.
4. It is difficult to carry out work because of the complaints. The feelings of discomfort are not fully relieved following such breaks.

Ideally this scale would require the interviewing of the drivers to be carried out at the workplace, but this may have alerted them to the fact that we were looking for links between driving and musculoskeletal troubles and led to error. For example, an increase in reporting of such troubles if involved in compensation claims or a decrease if subjects were concerned about keeping their job. An advantage of this scale is that the data are on a ranked scale giving it some quantitative meaning. By correlating these data with the data from the Health Questionnaire used by Ursin et al (1988), their findings supported the view that musculoskeletal troubles were not closely related to other types of health complaints, for example stomach aches, headaches, palpitations and colds.

Johansson (1994) added a question to the NMQ asking if the symptoms were thought to be related to current work in his survey of 450 subjects at eight large metal industry companies in Sweden. The fixed alternative answers were:-

1. The symptoms are solely related to present work.
2. The symptoms are partly related to present work, partly not.
3. The symptoms are solely related to factors other than the present work.

Again, although this questionnaire was completed anonymously, it could be argued that asking this question at work could bias the results. It may be, for example, that subjects were not always truthful for fear of jeopardising their job, especially in the case of the police survey. However the authors argue that it is essential to ask this question because an intervention programme based on the results of the NMQ without this information could fail to tackle the true problems. The fact that the general public interviews were carried out anonymously and away from work should have helped to minimise this problem although the addition of this question would have given more confidence in the results. In Johansson's (1994) study, the addition of this question increased the differences in the prevalence of musculoskeletal troubles between white and blue-collar workers. Similarly, Reisbord and Greenland (1985) suggest asking subjects for their perception of the physical demands of their job.

A criticism of these results is that not enough data were collected regarding mood, job satisfaction and other psychosocial factors. A single question was asked regarding job satisfaction and this may not have been sensitive enough to ensure confidence in the response to this question. Waddell (1987) believed that these factors were important and that the individuals attitudes, beliefs, psychological stress and illness behaviour with respect to low back pain affected their prognosis with regard to managing their condition. Also, as mentioned previously, it was reported by Battie and Bigos (1991) that out of all the variables explored it was only job satisfaction and emotional distress which were significantly correlated with reports of low back pain, although it was not reported if variables associated with exposure to driving were included. The same authors also reported that compensation related back disorders respond less well to treatment than those who are not pursuing compensation claims. Other authors had similar findings, for example Sullivan and Shimizu (1988) carried out an analysis of days off work (including for back injuries) among law enforcement personnel in Los Angeles and found that the factor most strongly associated with sickness absence was whether the individuals case for compensation was litigated or not.

The reasons for not collecting such data have been discussed in other chapters as being mainly the time involved in conducting such interviews (a short questionnaire was not found) and the fact that these interviews were to be carried out in public places. The police officers were interviewed at work and may have been suspicious of such questionnaires, in the light of the many changes in the police service. It would, however, be useful in future studies to use selected questions from scales such as Warr et al (1979) and Zigmond and Snaith (1983) in order to collect more detailed data regarding job satisfaction, motivation etc.

A general criticism of this work is the fact that total confidence cannot be given in the validity of the data such as the work tasks without the back up of objective measures. For example Baty et al (1986) casts doubt on studies where the absolute values of the risk factors have been determined from a questionnaire only. Also, Wadell (1987) reports that the subjective reporting of low back pain is influenced by the attitude of the individual, stress, restrictions on their activities and general illness behaviour. As stated, it was not possible in the time available to carry out the general public and police surveys, to validate such questions by comparisons with objective data, for example, the tasks at work, medical records and work histories. Care was taken to be as specific as possible in quantification of the data in the interviews, but this is an obvious area for future investigation.

7.3 Conclusions

1. The results of these surveys have provided further evidence to link exposure to driving cars with sickness absence due to low back trouble. For example, the odds of experiencing low back trouble if an individual drove for more than 20 hours a week as part of work were in the region of 2-3 times higher. Also these same individuals had a mean number of days ever absent with low back trouble which was six times higher than those who drove less than 10 hours a week as part of work.

2. As annual mileage increased there was a significantly higher frequency of reported discomfort, notably in the low back and neck. The prevalence of wrist / hand trouble was also more frequently reported with high exposure to driving cars.

3. Drivers of cars with the most adjustable driving packages, for example an adjustable seat and steering wheel, were found to benefit in terms of reduced sickness absence and discomfort.

4. Education programmes need to be set up to inform the driver and their employers of the potential risks of exposure to driving: Those particularly at risk being people who drive cars for more than half their working day. Encouragement, maybe even in the form of legislation, must be provided in order to improve the management and prevention of the problems associated with discomfort and driving. Any such training programmes should be fully evaluated.

5. Following on from point 4, any such training programmes will gradually increase awareness in employers and the general public, of the benefits of driving packages which offer more adjustments. It is hoped that eventually car manufacturers will be under pressure to offer suitably adjustable driving packages or risk a fall in their market share.

6. Having had a back accident / acute injury is highly likely to be predictive of future low back trouble. It is important to recognise these members of the driving workplace as being more at risk and so implement prevention strategies.

Part II

The Experimental Work

Chapter 8 Literature Review - Methodologies for Seat Evaluation

8.1 Introduction

The literature was reviewed for subjective and objective methods of seat evaluation which could be potentially used to predict seat discomfort. These were assessed in terms of their suitability for exploration for practical use in the automotive industry. There is a need in the automotive industry to derive objective measures for seat comfort assessment. It was hoped that these methods would provide designers with rapid, easily quantifiable data which would indicate which areas of the seat were contributing to seat comfort / discomfort at an early stage in the design process. Design changes could then be made followed by rapid reassessment. Subjective and objective methods are considered in this chapter. A large section is devoted to interface pressure measurement as it is a method which has been adopted by many car manufacturers.

8.2 Subjective Methods

Shackel et al (1969) regarded subjective measures as 'the ultimate criterion of comfort against which other more convenient and more objective measures may be validated'. Even 25 years later this statement stands unchallenged.

Subjective methods of evaluation have been traditionally used to obtain user opinion on seat designs. They have developed, and have become more widespread in use and sophistication. The more popular methods are briefly described below.

8.2.1 Chair Feature Checklist

The Chair Feature Checklist gives subjects the opportunity for direct comment on features of the seat which may give rise to discomfort. Features of interest such as seat height, lumbar support, backrest length, seat width and seat length are listed with a scale for subjects to indicate their response. Shackel et al (1969) used a descriptive scale and found this method had good discrimination ability for evaluations of upright chairs. Many other authors have also adopted this method: Drury and Coury (1982) administered a Visual Analogue Scale with their Chair Feature Checklist at the end of a 2.5 hour session and found that the results agreed with those of other evaluations which suggested that changes were needed in the backrest.

Reed et al (1991) used a similar scale with their Seat Feature Checklist and found that, although it was effective in discriminating between different seats, the relationship between seat feature evaluations and satisfaction with some of these features was inconsistent. For example, the subject's evaluation of seat width corresponded closely with the actual measurement, but seats which were preferred overall were evaluated as having longer backrests, even when this was not the case. Evaluation of the backrest could have been difficult as all the test seat backrests were sufficiently long for the subjects and it was subsequently concluded that if subjects were unsure about a feature they chose the rating based on their overall perception of the seat. The authors also compared their long term driving discomfort data (three hour simulation) with the Seat Feature Checklist results. At the start of the trial subjects gave higher ratings to car seats with a tighter back fit, stronger lumbar support and a more arched back posture. However the car seat which scored highest on these features was significantly more uncomfortable than the other seats in the mid and lower back areas after the three hours. They concluded that 'showroom style' analysis was inconsistent in predicting long term discomfort.

8.2.2 Comfort / Discomfort Rating Scales

The rating scale has been developed as a popular method of quantifying the subjective assessment of stimulus qualities (i.e. comfort). Guilford (1954) provided a thorough description and theoretical discussion of rating scales and problems with their use such as 'error of leniency', 'error of central tendency' and 'the halo effect'. The author recommends this as useful background reading in order to gain awareness of the wealth of experience of other investigators.

In addition Guilford (1954) provides a useful list of 33 peculiarities of rating scales to be considered by the experimenter, three examples of which are:-

1. 'Raters do much better if they are interested in the ratings they make'.
2. 'Raters should have sufficient time for making the ratings'.
3. 'The good rater is not necessarily self-consistent, nor is the self-consistent rater necessarily a good rater'.

In general, scales are of two types; the analogue rating scale, where subjects indicate the distance along a line a particular judgement of the stimulus should fall; and the category rating scale, where the subject makes a judgement from a number of ordinally positioned adjectives describing the stimulus. The analogue scale in its simplest form, with just two statements anchored at either end of the line, (for example 'very comfortable' and 'very uncomfortable'), can be criticised because a verbal description of comfort for any point along that line except the two ends may not be valid (Oborne, 1976). The category rating scale has the problem of only being ordinal in character and of only giving a crude assessment of the stimulus. Ellermeier et al (1991) developed a 'category partitioning' scale to directly judge pain intensity. Subjects selected a verbal category for the stimulus which was then 'fine tuned' using numbers i.e. very slight pain (1-10), slight pain (11-20), medium pain (21-30), severe pain (31-40) and very severe pain (41-50+). Although the validity and reliability of the scale were found to be good, this scale was only evaluated for direct judgements of a short duration pain stimulus and not discomfort over a period of time.

The general comfort scale developed by Shackel et al (1969) as part of a study exploring techniques for measuring seat comfort, was an early example of combining the two types of scale. The scale consisted of eleven statements, from 'I feel completely relaxed' to 'I feel unbearable pain', listed against a 10 cm vertical line which subjects marked to express their rating (Figure 22). The judgement was scored by rounding off the 'mark' to the nearest 0.5 cm and then doubling it to give a scale from 0-20. This scale could be criticised for the fact that the positions of the categories were not statistically determined. In use the scale was very successful at separating out the two worst chairs but it took more than three hours for clear differences to emerge between the other chairs. Since then, the scale has been used in many studies probably due to its apparent ease of use. Drury and Coury (1982) administered the scale every 30 minutes for 2.5 hours to evaluate a prototype chair and Thomas et al (1991) gave subjects the scale at the end of 40 minute driving simulations in order to evaluate four car seats. The results all suggest that while the scale is sensitive to large design differences, it may not be sensitive to more subtle ones.

Please rate the chair on your feelings now.

I feel completely relaxed
I feel perfectly comfortable
I feel quite comfortable
I feel barely comfortable
I feel uncomfortable
I feel restless and fidgety
I feel cramped
I feel stiff
I feel numb (on pins and needles)
I feel sore and tender
I feel unbearable pain

N.B. Not to scale.

Figure 22. General comfort scale of Shackel et al (1969)

Oborne (1976) attempted to combine the two scales and produce more accurate quantitative results. He asked 645 hovercraft passengers to mark their assessment of comfort along a rating line from 'very comfortable' to 'very uncomfortable' and also to assess it as being one of five category ratings. The interquartile ranges of positions on the line taken by each category phrase were obtained. If there was overlap between two phrases, the midpoint of this area was taken as the boundary line. The final positions of the descriptive phrases of comfort are shown in Figure 23.

Figure 23. The final position of the descriptive phrases of comfort along a 10 cm rating line by hovercraft passengers (Oborne, 1976).

Phrase	Position	N
Very comfortable (Very comfortable)	0 - 2.8	26
Comfortable	2.8 - 4.3	282
Just comfortable	4.3 - 5.6	271
Uncomfortable	5.6 - 8.8	62
Very uncomfortable	8.8 - 10.0 (very uncomfortable)	4

Oborne (1976) also used the technique to obtain scales of noise and vibration. The authors felt that the technique would be an improvement on just analogue or category scales, but also criticised the method in three main ways:-

1. The ratings scales obtained may only apply to the situation in which the data was obtained, i.e. the hovercraft service.
2. The category phrases had unequal representation of subjects, for example only 4 out of 645 were 'very uncomfortable'.
3. When ratings were near the boundaries of the phrases, there would be less confidence with their interpretation.

Obtaining scales specific to different situations, with equal subject representation by each category phrase would be very time consuming and yet with no real evidence that the scale was any more effective than the rank category scale.

Many scales have been developed, all very similar in style and some of those adopted to explore comfort with the automotive industry are listed: Hapsburg and Middendorf (1977) used a vertical line with eight scale points ranging from 'extremely comfortable' to 'extremely uncomfortable' for an overall comfort rating. Reed et al (1991) used a 10 cm line anchored at either end with expressions of 'no discomfort' and 'unbearable discomfort' to express perceived discomfort in four body areas. Wilder et al (1994) also used a 10 cm line as a Visual Analogue Scale of general discomfort. Gross et al (1994) used Likert scales to assess twelve aspects of the seat, with one representing very poor and five representing very good. The details of these studies are discussed more fully in Sections 8.3.2 and 8.4.5.

Hall (1972) used a five point rating scale (very good, fairly good, no special feelings, fairly poor, very poor) in a postal questionnaire designed to rate the comfort of cars that had been tested by 17 subjects during the last 12 months. The dangers of response bias due to reliance on memory does not need to be explained. However, he checked the reliability of the first questionnaire by sending out a second similar questionnaire six months later. Surprisingly the ratings were consistent, with 56% of the individual ratings actually identical for both questionnaires. To check that the ratings did not reflect hardened attitudes, the ratings for four questions were directly compared with the responses obtained during actual three hour test drives carried out by the subjects, with the results once again showing agreement. This study gives more confidence in the use of category rating scales as a means of evaluating car seats.

General comfort scales only provide a general impression of the seat; no information is obtained to identify parts of the seat which cause particular discomfort. Corlett and Bishop (1976) modified the idea of Allen and Bennett (1958) and developed a technique which could assess the distribution of discomfort in the body and so help to identify problems in a workstation design. They used a body diagram (Figure 24) and asked spot welders to indicate where they were most uncomfortable, next most uncomfortable and so on, covering areas of discomfort with small flaps as appropriate.

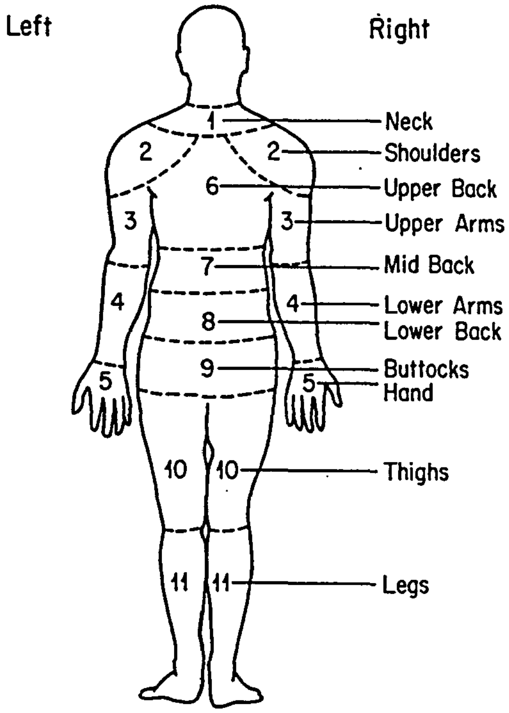


Figure 24. Body Part Discomfort map adapted from Corlett and Bishop (1976).

The technique was able to detect the beneficial effects (i.e. less reported musculoskeletal discomfort) of improvements to the machine. In the experimental situation, however, this recording procedure could be impractical and confusing for subjects. Consequently it has been adapted successfully to be easier to use many times for specific studies. For example, Thomas et al (1991) found that the technique was a valid discriminator between four types of car seat during a simulated 40 minute driving session, by visually comparing the body areas affected by each of the seats. These findings were consistent with general observations regarding the seats. Lee and Ferraiuolo (1993) used a numerical rating on a scale (0-10) of perceived comfort in ten body areas in an attempt to find correlations with EMG and seat pressure distribution data. Although the published data analysis was to be extended the early results were not consistent. This study is described in more detail in Sections 8.3.2 and 8.4.5.

8.2.3 The Method of Paired Comparisons

The method of paired comparisons is a psychological scaling method which can be used whenever stimuli (i.e. designs, colours, opinions etc.), can be presented in pairs. The technique is described and discussed in detail in Guilford (1954). Briefly, the stimuli, for example car seats, are numbered and listed in all possible pairings such that each car seat appears equally often first and second, no single car seat is in two successive pairs and the car seat's position first or second is alternated. In this way a number of checks for internal consistency are carried out on the scale. Subjects are then presented with the pairings and asked to choose between them on the criteria being scaled, for example aesthetics. A table can then be constructed showing the proportion of occasions one car seat is preferred aesthetically over another. A ranking of the car seats can then be calculated. Further extensive calculation will also generate a linear rating scale. Pairs of objects should not be so different from each other to give proportions that are very nearly 0 or 1. Also, if there are too many stimuli the number of judgements by subjects becomes too large (nine is the maximum recommended by Guilford, 1954), and subject fatigue is a possibility, almost certainly affecting the results. Although the technique can be only used for short term assessment, it is quick and easy to carry out as subjects are only required to make a simple judgement, i.e. a relative judgement of two products.

Grandjean et al (1973) used the technique with fifty subjects to evaluate twelve multipurpose chairs such as could be seen in an auditorium or dining room. Each subject carried out 66 paired comparisons giving a total of 3300 judgements. A ranked order for the twelve chairs was obtained which was used in conjunction with a three point scale commenting on comfort in different parts of the body to establish chair design recommendations. The large number of judgements that each subject had to carry out could have lead to fatigue and boredom, although the order of presentation was random to reduce the effect of this.

8.2.4 The Method of Fitting Trials

A fitting trial is an experimental investigation of the relationships between the dimensions of a product (workstation environment) and the dimensions of its users (Pheasant 1990a).

The procedure can be used to obtain the optimum dimensions or range of dimensions for a given workstation (for example a driving cab) and is briefly described here, based on Jones (1969). Firstly, a sample representative of the user population is selected for example, with respect to body dimensions of most relevance to the design (i.e. sitting height, hip breadth) and experience with the product. The essential dimensions of interest for the design are then decided and a mock-up is constructed using anthropometric data, so that each dimension can be adjusted independently over a wide range. For each subject the design feature, for example, the steering wheel is then moved at discrete increments from one extreme to the other. At each setting the subject is asked whether the position is satisfactory or unsatisfactory for a given criteria whilst carrying out a task, such as turning the steering wheel. In this way the optimum location or range of locations for the component is found. The technique is then repeated independently for any other design feature of interest, for example the pedals. In the days of Jones (1969), the results of the fitting trials exploring driving posture lead them to the conclusion that European cars were too small for comfort.

8.2.5 The Work of the Vehicle Ergonomics Group (VEG)

The Vehicle Ergonomics Group (VEG) based at Loughborough University has carried out research on the driving workstation since 1981 and has scientifically evaluated more than 100 cars as either production or prototype models (personal communication with Porter, 1994). Much of this work was for car manufacturers and therefore was subject to confidentiality with regard to publishing. However, their experience lead to an established methodology for the 'best practise' for assessment of car seats using subjective data. The group uses road trials involving subjects driving a 60 mile test route, encompassing a range of road types i.e. motorway, country roads and town driving. Subjects are selected (usually n=20) for each seat being assessed (i.e. driver, front seat passenger, rear seat passenger) and they represent the full range of anthropometric dimensions (stature, hip breadth, arm length etc.), for both males and females and usually cover the 18-65 age range depending on the market at which the car is aimed. During the 2.5 hour (60 mile) test route drive subjects complete 'body map' comfort rating scales (5 or 7 point) for 20 body areas and a series of questions commenting on design features of the car such as the hardness / supportiveness of the seat, the positions of the controls and the general ride of the car. By calculating the percentage of subjects who report discomfort (scoring above the midpoint) at each stage of the trial, this medium term drive gives an indication of how discomfort in different body areas develops over time.

8.2.6 Summary of the Subjective Methods

Although many of the subjective methods described are frequently used by ergonomists and psychologists and often provide valuable information, they can be time consuming especially in terms of selecting appropriate subjects, the length of trials etc. The Vehicle Ergonomics Group (VEG) take three months for full scale evaluations of as few as three competitors cars. This is costly for car companies to undertake, particularly in the early stages of a design. At present however they are fundamental to much research with human subjects and should not be easily dismissed.

8.3 Objective Methods

Car manufacturers have always been keen to use objective evaluation techniques to obtain rapid and quantifiable data. In this section appropriate techniques identified by the literature are described and discussed with regard to their suitability. Interface pressure measurement is discussed in more detail because of long-term and current interest by many researchers in the automotive field.

8.3.1 Stature Shrinkage

Precision measure of stature is a relatively new concept, first described by Eklund and Corlett (1984). It utilises the fact that spinal discs have elastic properties with gradual compression or creep when loaded and recovery when unloaded. Eklund and Corlett (1986a) demonstrated that the rate of shrinkage varied with the amount of biomechanical loading (dynamic and static) and that height was regained when the individual adopted a position of rest. Diurnal loss was normally 15 mm (Eklund and Corlett, 1986a), with 54% of shrinkage occurring within the first hour of getting up (Tyrell et al, 1985). Stature loss was regained with sleep at night with 70% being regained in the first half of the night (Tyrell et al 1985).

The method is non-invasive, and in one study by Eklund and Corlett (1986a) was sensitive enough to discriminate between different seated postures for a pushing task; forward viewing (low backrest), sideways viewing (high backrest) and a sit-stand seat (low backrest and limited knee space). However, a number of drawbacks were apparent for practical and reliable use of the technique. Some training of the subject and experimenter is required for repeatability of the measurement, which can be time consuming (20-60 minutes per subject as advised by Eklund and Corlett 1986b). It also required the availability of specialised and well maintained equipment. The method was highly sensitive to patterns of 'activity' during the day, subject stress and motivation such that comparison of the results taken on different days would not be valid. Careful instruction of the subject to standardise his activity with detailed notes regarding sleeping time, getting up time etc., were required. In addition, Foreman and

Linge (1989) realised the importance of allowing the subject to stand for two minutes before measurement to avoid the confounding effect of heel pad compression in the foot. As well as practical difficulties and the administration of the technique there were also a number of problems foreseen in using the technique to evaluate car seats. Firstly the data do not give any indication of which parts of the spine had most spinal compression and therefore which parts of the seat were causing discomfort and secondly a large number of subjects would be required to investigate some of the more subtle differences between prototype car seats. At this stage there appears to be no potential advantages of using this technique in the automotive industry, given the time and care required for reliability of the measurement. It could be that a more effective use of this time would be to carry out road trials and simply ask subjects about their discomfort.

8.3.2 Electromyography (EMG)

Electromyography, the recording of myoelectric signals, has been used in many seating studies. Although a high correlation exists between EMG activity and the muscles used in a task (Hagberg, 1981), the literature was not conclusive about its usefulness in evaluating car seats. Wilder et al (1994) measured the erector spinae muscle activity at the 3rd lumbar vertebrae level of the spine of six males during ten minute truck-driving simulations. The median frequency EMG data were compared for each of two types of truck-seat, with subjects adopting three different driving postures. The EMG data were sensitive enough to distinguish between postures, for example, unsupported sitting in both seats produced the greatest muscle loading of the posterior trunk muscles, however no significant differences were found between the two types of truck seat when posture was supported.

An example of the uncertainty that exists in interpreting EMG data can be seen in a study by Lee and Ferraiuolo (1993). EMG readings were taken in an assumed driving position from 100 subjects sat in 16 identical looking but different seat designs. Design parameters for the seats (foam thickness and hardness, back contour and angle, cushion angle, spring suspension rate and side support) known to contribute to seat comfort were set at levels above and below the current design for selected standard seats. Seat designs consisted of a statistically balanced mix of these parameters. The six highest EMG readings for the neck muscles corresponded to the six best subjectively rated seats, shoulder and medial hamstrings predicted four out of six of the best seats and other muscles predicted three out of the six best seats. No attempts were made to explain how these predictions were made, but they concluded that further studies were needed to explore the relationship between EMG data and subjective seat comfort in studies of the long term driving situation.

A major problem in interpreting EMG data is the confounding effect of voluntary muscle activity, caused by naturally occurring postural shifts over a period of time and by the operation of the controls. Reed et al (1991) studied four different production seats with eight male drivers, using an adjustable driving simulator. They found that the more reclined seat put more demands on the abdominal muscles during small postural shifts, the converse being true for the more upright seats. However, this high muscle activity bore no relation to the discomfort experienced and, as discussed in Chapter 2.3.4, the ability to carry out these small postural shifts is actually important in seat comfort.

Sheridan et al (1991) used EMG data in their study of physiological and psychological driver fatigue. Five subjects drove a four hour, 200 mile, test route in each of four different seats; two production seats, a hard plywood seat with no contouring and a thinly padded moulded fibreglass bucket seat. The median frequency and Root Mean Square (RMS) values of the EMG signals from eight back muscles were calculated. Although this study was mainly concerned with measurement techniques to quantify driver fatigue, some of their findings were of interest. Both the bucket seat and the plywood seat had high levels of muscle activity (calculated by RMS), but it was hypothesised for different reasons. The plywood seat was hard with no shaping and subjects were forced to relieve areas of pressure in their bodies by excessive movement. In contrast the bucket seat was highly contoured, constraining body movement, such that attempts to relieve symptoms were ineffective. In this case although body movement was low, the increased muscle activity was thought to represent increased muscle tension. Differences between the two prototype seats were also not conclusive, again indicating that the method is only suitable for detecting large design differences.

Despite the advantage of portability, there were other practical problems in relation to the use of EMG in evaluating car seats. These are briefly listed as follows:-

1. Individual differences between subjects means that each subject needs to establish their own base EMG data and muscle activity pattern. It is difficult to then set thresholds for levels of EMG activity indicating for example, a comfortable seat.
2. It is likely that the sensors themselves are obtrusive to the subject and may affect subjective comfort data.

3. EMG activity in the trunk whilst sitting is low and easily affected by noise interference such as heart beat, reducing the quality of the signal. Consequently recorded data may have large relative errors.
4. It is impossible to locate the exact location of the electrode on the muscle and subjects would need to wear the electrodes for the duration of any trials. This becomes impractical if several long trials are involved.

8.3.3 Task Performance

Chairs and workstations that minimise discomfort can have a positive effect on productivity (Zacharkow, 1988). However the literature is disappointing with regard to showing performance differences, indicative of the difficulties in controlling all the variables that can affect performance, for example, mood, stress, motivation, fatigue, previous learning, cultural influences etc. Cushman (1984) and Life and Pheasant (1984) both studied the effect of keyboard heights on performance, but no significant differences in keying rate were found and Bendix and Jessons (1986) study (four 15 minute experimental conditions), looking at the effect of wrist supports on typing tasks, also revealed no differences. Happ and Beaver (1981) examined performance during an unpaced video-coding task, consisting of a two hour laboratory experiment, and found no performance decrement despite fatigue symptoms. They concluded that a demanding, lengthy task was necessary to clarify the posture / performance relationship.

Some literature was available where performance did correlate with posture or discomfort but the links were tenuous. Thomas et al (1991) assessed driving performance using a 40 minute video game based on good, accident free driving. They found highly significant ($p<0.0005$) differences with gender, females scores being less than males, but no differences between the seats. They then hypothesised that as females were generally more uncomfortable than males in the seats, this reflected the performance scores. No attempt was made to discuss other possible causes of the lower scores in females such as poor motivation, or lack of familiarity with video games etc. In another study by Bhatnager et al (1985), subjects inspected printed circuit boards for three hours looking for errors. Performance measures were missing a fault (search error) and reporting a non existent fault (false alarm). They found decreased task performance was associated with increased forward trunk inclination, increased perceived discomfort and increased frequency of postural changes. In this three hour task however, the decrease in performance may not even have been due to postural discomfort, but to other influencing factors such as boredom with a repetitive task. In the light of the literature, it was felt by the author that performance would not be a good predictor of comfort / discomfort in car seat design.

8.3.4 Posture Analysis

Posture recording has existed for many years with its origins in choreography. It can be used as a means of objectively describing and analysing driving posture. A number of techniques have been developed appropriate to the relatively static postures encountered whilst driving. Those considered with regard to their suitability for this study are summarised in Table 46.

Some of these approaches are expensive in terms of equipment and resources, others require training and experience. The method of using a goniometer is quick, inexpensive, requires little training for reproducible results and was thought appropriate for use in static driving trials.

Table 46. Posture analysis techniques

Method	Description	Considerations	Reference
Posture targeting	Body parts assigned with a set of concentric circles or targets and deviations from standard positions are marked.	Although suited for static postures, some training and experience necessary for reliability.	Corlett et al (1979)
Ovako Working Posture Analysing System (OWAS)	Posture described as a 3-digit code according to the positions of the back, upper limbs and lower limbs.	Easy to learn, but lacks the precision to describe relatively static postures.	Karhu et al (1977)
VIRA	Two video cameras record work posture. Neck and shoulder positions classified into categories for laboratory analysis.	Video cameras and computer package required. Expensive to set up.	Persson and Kilbom (1983)
Goniometry	Markers placed on specific body points, subjects 'freeze' in a position. A large goniometer is used to measure body angles.	Method can be invasive but practical to set up.	Life and Pheasant (1984) Hunting et al (1981)
Photographs	Markers placed on specific body points. Angles measured from photographs or projected image from agreed guidelines.	Method non evasive. Practical to set up. Training not required. Care needed to avoid inaccuracy.	Mandal (1984) Grandjean et al (1983) Bhatnager et al (1985) Bridger (1988)

Curve Meter	Flexible stick placed on individuals back. Distortions in the sagittal plane measured.	Too many angles required for practical use with car driving posture.	Lepoutre et al (1986)
Cartesian Optoelectronic Dynamic Anthropometer (CODA)	Reflective markers placed on the body. The computer can recognise markers and calculate the posture.	Equipment expensive and difficult to obtain.	Corlett (1990)
Posture classification system	Video camera records work posture. Trunk position deviations analysed from standard 'neutral' postures.	As VIRA	Keyserling (1986)

Recommended postural angles for comfort based on calculations by Rebiffe (1969) and Grandjean (1980) are discussed in Chapter 2.3.5. Reed et al (1991) following their three hour driving simulation experiments, concluded that there was a need for detail regarding the actual postures individuals adopt. They felt that there was a dilemma for car seat designers in obtaining a balance between 'prescribing' a seated posture and accommodating a 'preferred' posture. In their experiments design features such as a contoured backrest (incorporating a lumbar support) increased back discomfort, often because the backrest angle selected by the subjects caused their lower back to lose contact with the lumbar support. They felt designers should consider the design parameters required for the support of preferred postures whilst taking into account the principles of reducing postural stress.

8.3.5 Other Objective Techniques

Intra-abdominal pressure

A correlation exists between intra-abdominal pressure and stress on the lumbar spine sufficient to investigate load handling, although females showed greater variability than males (David, 1985). Examples of the use intra-abdominal pressure to quantify truncal stress are given by Stubbs (1975), who used the technique to examine 'lifting' and 'pushing' forces in industrial workers and also to aid the evaluation of two different bed designs with respect to four lifting conditions in nurses (Stubbs et al, 1987). Again investigating patient-handling techniques using intra-abdominal pressure data, Pheasant and Stubbs (1992) were able to calculate an index of risk assessment of back injury for nurses. The technique's ability to detect changes in the sitting posture however is not so certain. For example, Nachemson et al (1986) did not find intra-abdominal pressure to be an indicator of spinal loading in upright, forward leaning and relaxed sitting postures. Uncertainty about the technique's sensitivity to the sitting posture and the fact that medical supervision is needed using the radio-telemetry pills made this an unsuitable method.

Intervertebral disc pressure

Andersson and Ortengren (1988) measured disc pressure at the 3rd lumbar vertebrae in a series of different sitting postures. They were able to show that disc pressure was lowest in the relaxed postures of leaning against a backrest and leaning forwards with the hands supported by the desk, and highest in an upright posture. They also looked at the effect of different depths of lumbar supports, and found that disc pressure was even lower than standing when the seat cushion to backrest angle was 110 or 120 degrees and the depth of the lumbar support was 50 cm . Despite these important findings for seating research, the procedure of inserting needles into the disc is invasive, often uncomfortable for the subject and must be performed by specialised staff.

Volume of the foot

There are three main reasons for an increase in foot volume when sitting (Pottier, 1969):-

1. Thigh compression obstructs venous return and because of the elasticity of the walls of the vein, blood fills the veins. This accounts for an increase in foot volume amounting to 25 per cent of the increase caused by the hydrostatic pressure.
2. Increased hydrostatic pressure in the veins, forces the flow of fluid through the capillary membrane into the interstitial space. Without contraction of the calf muscles aiding venous return, 'swelling' occurs.
3. Thermal increase causes vaso-dilation adding to the effect of hydrostatic pressure.

The method only reflects the effect of the seat on the lower limb and once again there is doubt about the technique's suitability for distinguishing between actual production seats.

8.4 Interface Pressure Measurements

8.4.1 Introduction

Interest in seated pressure distribution arose because the tissues covering the ischial tuberosities can be subjected to extremely high pressures sufficient to reduce blood circulation through the capillaries. If there is no readjustment of body position, metabolite build up and the symptoms of aches, pain, discomfort and numbness occur (See Section 8.4.2). It then seems logical in any seating design that areas of high pressure should be minimised and pressure uniformly distributed across the sitting region. There are high hopes in the automotive industry that interface pressure measurement will be able to predict areas of discomfort in car seat design at an early stage and many companies are already using this technology. In this section the literature regarding interface pressure measurement is reviewed in detail.

8.4.2 The Effects of Pressure on Body Tissues

Although much of the literature regarding the effects of pressure on the human buttocks was motivated by research into ischaemic ulcers, many of the principles are relevant to seating research in normal subjects. When a normal person sits, local pressure causes tissue deformation impeding blood and nerve supplies especially under a bony prominence such as the ischial tuberosity (IT) or sacrum. After some time discomfort (pain, numbness, tingling etc.,) is experienced and the person adjusts his or her body position, in fact a person is unconsciously shifting position all the time. If only very slight variations in posture are allowed, such as at a driving workstation, severe pain may result after some hours. In people who have reduced sensation or who cannot change their body position, for example those with spinal injuries, mechanical tissue damage can easily result i.e. ischaemic ulcers, more commonly referred to as pressure sores.

By carrying out anatomical dissections of six human autopsy specimens, Daniel and Faibisoff (1982) found that soft tissue coverage of the sacrum was skin (1-3.5 mm), subcutaneous fat (5-30 mm) and no muscle. In the sitting position there was also no muscle coverage over the ischia as hip flexion causes the gluteus maximus to move superiolaterally exposing the IT's, such that in sitting tissue coverage of the ischium was skin (0.5-3 mm) and subcutaneous tissue (5-60 mm) with no muscle.

Soft body tissues undergo deformation but are virtually incompressible (Chow and Odell, 1978). In experiments by Cattel (1936) hydrostatic pressures in excess of 1,000 million mmHg were required before significant changes in cellular function were observed, leading Newson and Rolfe (1982) to conclude that the role of pressure in the formation of ischaemic ulcers was to restrict blood flow. Classic studies with rats (Hussain, 1953) and dogs (Kosiak, 1961) were carried out, concluding that constant pressures were more damaging to tissue (including muscle) than alternating (cyclic) pressures. Application of very high pressures (500 mmHg) even for a short duration (two hours) produced lasting changes in the larger blood vessels, such as venous thrombosis, resulting in tissue ischaemia which continued even after the release of the pressure (Kosiak, 1959). Evenly distributed pressure was well tolerated unlike localised pressure which induced a pressure gradient in tissues causing vascular compression (Hussain, 1953).

The skin directly over the IT's is actually well adapted for weight bearing by having a rich blood supply resulting from abundant capillary loops, aiding reactive hyperaemia (Edwards and Duntley, 1939), whereby on the release of pressure tissues starved of arterial blood were instantly flooded with oxygen. The amount and duration of this blood flow was proportional to the needs of the tissues. Muscle fibres were more sensitive to localised constant pressure than skin (Hussain, 1953; Kosiak, 1961; Daniel and Faibisoff, 1982) eventually changing its morphology and so function over time.

Bennett et al (1979) points out the emphasis of research on normal (vertical) pressure and the need to consider shear (tangential) forces in capillary occlusion. Their experiments concluded that shear force alone would not produce occlusion as it is only the existence of high pressures which allows the stable development of large shear forces. However, although pressure is the primary force, the pressure value required to produce occlusion can be halved when accompanied by sufficient shear. For example, under high shear conditions occlusion occurred at 60 - 80 mmHg comparable with low shear condition pressure values of 100 - 120 mmHg to produce occlusion. Other authors specifically recognising the importance of shear forces include Dinsdale (1974), Chow and Odell (1978) and Bader and Barnhill (1986).

8.4.3 The Relationship Between Body Build, Posture, Gender and Pressure

The huge range of variation in interface pressure values exists due to individual differences, such as tuberosity size, shape, curvature and roughness; body size and weight; thicknesses of skin, fat and muscle (Herzberg, 1972). However in a study by Yang et al (1984) using 39 normal subjects (male and female), no correlations were found between either height, weight or the Reciprocal Ponder Index (a measure of body build). Also in Holley et al's (1979) study of 12 subjects (both sexes) no correlations were found between weight and mean pressure when subjects sat on four different foam cushions. Perhaps the variables of height, weight etc., were too crude, and detail regarding skin, fat and muscle thicknesses or IT size was needed especially when posture was not held strictly constant.

Garber and Krouskop (1982) conducted an experiment with 70, mainly male (n=55), patients with spinal cord injuries. They found that thin subjects (< 90% of their ideal weight) had significantly higher pressures over a bony prominence than average weight or obese patients. They even found that with these patients the maximum pressure values were not significantly different between sexes whether over a bony prominence or soft tissue. For example, over a bony prominence the maximum seated pressure was 78.6 mmHg (SD 4.4) in males and 77.5 (SD 5.82) in females. It must however be noted that there were only 15 females in the sample, although the paper does not suggest that they were any different in body build to the males i.e. all thin. It was likely that many of the subjects in this study had muscle atrophy in the buttock thigh area allowing the IT size and shape to produce sharper gradients and peak pressures. But, their findings do suggest that obese and average weight patients are better able to diffuse pressure over a larger area and that body build has a significant effect on maximum pressure values.

Posture does seem to be more clearly associated with seated interface pressures. Linden et al (1965) found that the leg and trunk positions were important factors in determining seated interface pressures: Peak pressure over the IT's on one subject in the sitting position increased from 60 mmHg to 100 mmHg by supporting the feet, with the effect of decreasing the seated area over which pressure could be distributed. Bush (1969) too, in his study involving seven relatively thin subjects, found significant differences in both thigh and IT pressure for three different leg positions (legs dangling, feet supported on foot plates, legs supported at the calves). Shen and Galer (1993) systematically observed the interface pressure with eleven subjects, for six postures produced by changes in chair angle and found that the pressure measures were effective in reflecting postural differences. For example when the seat angle was changed from 10 to 20 degrees, the maximum seat pressure changed from 116 to 100 mmHg.

Yang et al (1984) also noted significant differences in pressures between sexes; a mean IT pressure of 109 mmHg (SD 28.2) for males compared with 79.9 mmHg (SD 15.6) for females. Zacharkow (1988) attributed this to males having less subcutaneous fat in the buttock and hip regions, being more heavily built above the pelvis and the IT's and acetabula (the sockets for the head of the femur) being closer together in males, with the ischia more inverted. Sember III (1994) reported that over 40 years of age the 'padding' in the buttocks area becomes more equal between the sexes. Females however do tend to have an increased backwards tilt of the sacrum, thus exposing the female to higher pressures in the sacrococcygeal area when in a slouched sitting posture (Johnson, 1981).

8.4.4 Pressure Measurement Technologies

Technologies for measuring interface pressure have been numerous and creative, attempting to balance the desirable with the practical. Early research was motivated in response to the medical profession's need to quantify interface pressure as a means of preventing ischaemic ulcers (pressure sores). A good description of these early systems is given by Treaster (1987). This still remains the main application of the technique today with pressure sores still costing the National Health Service a considerable amount of money. In fact, much of the pressure measuring equipment commercially available originates from the clinical setting. This equipment often has to be modified or compromises made for use in other areas such as car seats. Engineers faced complex problems when designing such devices. Ferguson-Pell (1980) usefully provides the following important design criteria:-

1. The diameter of the individual sensors should be small relative to the interface curvature to ensure good contact with the skin and for the pressure acting on the sensor to be homogenous. A maximum diameter of 14 mm is recommended for measurement of peak pressure.

2. Maximum sensor thickness is difficult to estimate due to the different foam hardnesses and individual differences in the mechanical properties of the tissues. Calculations using various hypothetical situations of flesh and foam thicknesses, demonstrated that to achieve optimum accuracy a maximum of 0.5 mm is recommended for peak pressure measurement.

3. The sensors should be flexible to conform to the curved surfaces of the body without producing error associated with the distortion of the sensing mechanism itself. He suggests a small sensor aspect ratio (the ratio of sensor thickness to diameter) to ensure this, as well as reducing measurement error.

4. Repeatability of the measurement is essential for reliability of the readings.

5. The sensors should be durable and the readings not significantly affected by environmental temperature and humidity. If the latter is true, suitable protection is required.

6. The calibration technique should simulate conditions at the interfaces being measured.

7. Consideration should be given to the effects of hysteresis, i.e. whether the pressure output depends upon whether the applied pressure is increasing or decreasing. This would reduce repeatability.

In addition, any pressure sensing device used for seat pressure measurement should be unobtrusive to the seated subject, have optimum sensitivity and range, be linear in the pressure and resistance relationship over a high range, be easy to use and be cost-effective (Gross et al, 1994).

Pressure Sensors

There are three main types of sensors which have been used to measure seat-buttock interface pressure: electronic (capacitive, resistive, strain gauge), pneumatic and electro-pneumatic.

Electronic transducers consist of a deformable component upon which a sensing element is attached. Applied force resulting in variations in resistance or capacities can be measured electrically. This type of technology has been used in many studies, for example Bush (1969), Herzberg (1972), Drummond et al (1982), Cooper et al (1986), Congleton et al (1988), Lee and Ferraiuolo (1993), Podoloff (1993) and more recently by Gross et al (1994) and Kalpen et al (1995). Although earlier technologies were unreliable in terms of repeatability and validity, recent developments in electronics technology have allowed reproducible and accurate measurements. This technology however continues to be expensive at the time of writing.

The pneumatic sensor is an air cell connected to an air reservoir. In order to inflate the sensor, the pressure in the air reservoir must have the same pressure as that applied to the sensor. When inflation pressure equals applied pressure, the volume of air in the sensor increases suddenly. The pressure in the air reservoir at which this change in resistance to pressure occurs is recorded as applied interface pressure. This principle was used by Bader (1982) and Bader et al (1984), in the development of what is now the commercially available Talley Pressure Monitor (TPM). Eckrich and Patterson (1991) also developed a pneumatic pressure bladder grid and concluded from a review of the literature that this was the system of choice for the investigation of overall pressure distribution.

Electro-pneumatic sensors have electrical contacts on the inner surface of a flexible, inflatable sac. Air is pumped into the sac and when internal and external pressure are in equilibrium, the electrical contact breaks and pressure at this point is recorded as interface pressure. Robertson et al (1980) designed a 28 mm sensor for clinical use which when uniformly mechanically loaded on a flat surface gave readings within two per cent of calculated values. The authors realised the need for a smaller sensor, but felt that their sensor compared favourably with other commercially available sensors at that time.

Other pressure measuring devices

Linden et al (1965) used the principle of spring compression to develop a 'bed of springs and nails'. Despite limitations inherent in the design, compression of the independently calibrated springs in a seated or lying position could be measured to plot the distribution of pressure. Small load cells arranged in a matrix sandwiched between cloth were used by Kamijo et al (1982), although no other technical details were given. Shields (1986) developed an ischiobarograph in which a television camera detected changes in light intensity from the underside of a plexiglass sheet. These signals were then converted into three colours calibrated to represent different pressure intervals. Again based on optical principles, Treaster (1987) developed an experimental chair to measure pressure which utilised the principle of total internal reflection. The seat and backrest consisted of an acrylic base overlaid with pedobarograph foil. Images of light intensity patterns on the underside were recorded with a low-light sensitive video camera and converted to pressure values, providing continuous measurements of pressure intensity. Bennett et al (1979) developed a sensor to measure pressure, shear and blood flow. The 2.5 cm sensor actually consisted of four separate sensors (two pressure, one shear, one blood flow) and the although much was learned from the challenge, the authors conclude that there was scope for improvement.

8.4.5 Discussion of Pressure Measurement Studies

The literature regarding interface pressure measurement was limited in both quantity and quality. There was great variation in the range of recorded seated interface pressure values (Table 47) due to varying body types, technologies and seat surfaces with the result that it was difficult to reach any consensus about normal ranges of pressure. There was even general disagreement as to when capillary occlusion occurs due to the techniques of measuring the pressures: 32 mmHg was commonly quoted (Kosiak, 1959 and Herzberg, 1972) and 38 mmHg by Sember III (1994), but Newson and Rolfe (1982) demonstrated cut-off pressures to be 300-360 mmHg, a figure higher than any previous measures.

Table 47. Brief summary of the interface pressure values taken from the literature.

Author	Brief Description	Examples of Interface Pressure Values (mmHg)
Linden et al (1965)	Used a 'bed of springs and nails' with 3 subjects, movement of each nail head could be converted into a pressure reading.	Seated on 'bed of springs and nails':- IT pressure = 75-130
Bush, C. (1969)	Pressure sensitive transducer used to measure IT and thigh pressure of 7 thin males and females while varying wheelchair seat length and leg position.	Feet supported by wheelchair footrest in 16 inch seat:- IT pressure = 78-1500 Thigh pressure = 26-233
Herzberg (1972)	Used a thin 'pressure measuring blanket' of closely spaced, 1cm flexible capacitors. 35 male subjects.	With hard 'experimental seat' variability of IT pressure = 0-3102
Drummond et al (1982)	64 strain-gauge resistive transducers fabricated on an aluminium plate were used to measure the distribution of seated pressure during balanced and unbalanced sitting. 15 normal subjects and 3 subjects with sitting balance problems were measured.	Pressure distribution (whilst sat on the aluminium plate) of body weight for normal subjects was as follows -18% over each IT -21% over each thigh -5% over the sacrum Subjects with sitting balance problems showed unequal pressure distributions.

Kamijo et al (1982)	308 small load cells were arranged in matrices for the back and seat cushion, in order to measure pressure. 43 car seats were evaluated with one male subject.	On a comfortable car seat they suggest:- IT pressure = 45 Lumbar = 11.25-18
Newson and Rolfe (1982)	Electro-pneumatic pressure measuring device used to take IT pressure measurements of 3 healthy males.	Complete occlusion of the underlying capillary bed:- IT pressure = 300-360
Yang et al (1984)	Used a pneumatic cell pressure transducer with 39 subjects (male and female)	Mean IT pressure = 97.7 sitting on a wooden chair Mean IT pressure = 64.3-70.4 with different cushions
Sheilds (1986)	Ischiobarograph used to record pressure in 10 subjects seated on a hard surface with and without a lumbar support.	IT pressure = 300 (without lumbar) IT pressure = 80 (with lumbar)
Congleton et al (1988)	Pressure measured using geometrically arranged transducers on a conductive foam blanket with 12 male subjects. Three very different chairs were used:- a surgeons stool, office chair and neutral posture chair.	Examples of data:- Surgeons stool with 127 degree trunk thigh angle: -Average Buttock PMean = 60 -Average Buttock PMax = 152 Office chair with 127 degree trunk thigh angle: -Average Buttock PMean = 22 -Average Buttock PMax = 66

Riley and Bader (1988)	4 normal subjects sat in a wheelchair with the back canvas removed. Interface pressure was measured using a pneumatic device (The Oxford Pressure Monitor) on 4 different seat bases (angles ranging from 5 degree back tilt to 10 degree forward tilt).	5 degree back tilt: -Mean IT pressure = 56-120 -Mean thigh pressure = 21-41 10 degree forward tilt: -Mean IT pressure = 50-80 -Mean thigh pressure = 18-25
Kurz et al (1989)	This paper makes recommendations regarding ergonomic vehicle seat design. No method / reference given regarding pressure measurements.	Recommendations: -pressures directly beneath the IT's to be 75-225 -pressures immediately around the IT's to be 60-113 -pressures in the remaining cushion and backrest to be 15-60
Treaster and Marras (1989)	Pressure measuring equipment involved the principle of total internal reflection, such that the light intensity correlated with the pressure intensity. Eight subjects were measured in an experimental chair in different postural conditions.	No actual pressure values given. Found that both seat and backrest angles affected pressure distribution.
Eckrich and Patterson (1991)	Used a 50 cell pneumatic pressure bladder grid to measure pressure. 2 healthy subjects sat in a wheelchair and dynamic and static measurements were taken.	Static pressures: -Seat pan PMean = 27.8 -Seat pan PMax = 135 Dynamic pressures: -Seat pan PMean -lowest = 14.2 -Seat pan PMax -lowest = 42 -Seat pan PMean -highest = 37 -Seat pan PMax -highest = 178

Matsuhashi (1991)	No information given regarding pressure measuring device.	PMax of the seat pan of 4 car seats ranges from 133-167
Gross et al (1994)	A pressure measuring mat with 225 sensors on each of the seat pan and backrest was used to measure pressure. This uses resistance as a transducer to represent pressure. More than 1100 seat -subject combinations (50 seats) were evaluated in short trials (5-10 minutes)	The units of measurement are not given, therefore it is difficult to interpret the values found.
Sember III (1994)	A Force Sensing Array made of 225 force sensing resisters was used to measure pressure. No information given regarding experimental design.	Advises, the maximum pressures that can be sustained under the IT's without discomfort for 15 minutes are: -62 (men under 30 and women under 40) -26 (over 40's) -15 (the elderly)

Some of the earlier studies were limited by the technology available at the time (for example Linden et al, 1965; Bush, 1972; Herzberg, 1972 and Drummond et al, 1982). Nevertheless useful experience was gained in the quest for improved equipment. Pressure transducers were a potential source of error in earlier studies according to Treaster (1987). For example, if the transducer was fixed with tape to the seating interface the tension of the tape may create error; the thickness of the transducer may cause artificially high pressures on the tissues and the poor resolution of large transducers adds error. Other potential sources of error with transducers are hysteresis, where the output of the sensor responds differently to increasing load compared to a decreasing load; creep, where there is a percentage increase in output over time while the applied pressure remains constant; and temperature dependence. Many electronic and electro-pneumatic matrices were inflexible causing a 'hammock effect' which prevents the body from sinking into the supporting surface, resulting in measurement errors, especially with very compliant cushioning materials. Intrusive pressure measuring devices also may have an effect on subjective data collected acting as an additional interface. Although equipment based on optical principles may eliminate potential error as suggested by Treaster (1987), their use was not suitable for the flexibility required for different measuring situations.

Air filled sensors measure peak pressures regardless of the direction of the force. Ferguson-Pell (1980) felt that reliable pressure measurements could only be obtained if sensors responded differently to any tangential forces or these forces were decoupled, but if the main interest was overall pressure distribution then pneumatic sensors were the best method. Bennett et al (1979) believed that these tangential forces combined with peak pressure were causative factors in skin blood flow occlusion.

Ferguson-Pell and Cardi (1991) evaluated three commercially available pressure measuring systems to determine the ease of use, data presentation, accuracy, reproducibility, inter-sensor variability, hysteresis, linearity and stability of the equipment. The Talley Pressure Monitor Mark 3 (a pneumatic system) produced the most accurate and repeatable measurements but was limited by scan rate and ease of use. The VERG force sensing array (transducers) and Tekscan systems (force sensitive conductive ink) showed hysteresis and creep but were more practical to use.

Reed et al (1991) measured the interface pressures in the lower back and buttocks area of eight male subjects sat on four different car seats for separate three hour driving simulations. Only 12 polymer film sensors (6 on the seat and 6 on the backrest) were positioned on the car seats (front, middle, rear and high, middle and low), so consequently it was not always possible to reference to anatomical landmarks. However they found that higher levels of discomfort were reported in seat areas of increased pressure, but statistical analysis was not reported. Despite the limitations of the small sensor size and the fact that only male subjects were used, this study indicated that pressure sensor data could be useful in explaining car seat discomfort.

The number of subjects in some studies was small. For example, Kamijo et al (1982) used only one 25 year old male subject to obtain seated pressure maps of 43 seats and yet a recommendation of 11.25-18 mmHg was given for a 'supportive' lumbar support. The judgements of these 43 seats by 15 subjects for classification into comfortable or uncomfortable seats, were 'quick showroom style analysis' under static conditions. The recommendation for a lumbar support could be completely different after sitting for several hours. Other studies (Kurz et al, 1989; Matsuhashi, 1991 and Sember III, 1994) also make recommendations of optimal pressures but no method or references were given regarding experimental design (Table 47).

Surprisingly few studies have attempted to correlate seat comfort with interface pressure. In the study by Kamijo et al (1982) 43 seats were evaluated as being comfortable or uncomfortable, although the comfort scale used was not described. The time duration of the evaluation is also not given but is assumed to be short. Their results showed that static pressure distribution 'approximately correlated' with the difference between comfortable and uncomfortable seats. However this finding was based on the patterns of pressure readings of one subject matching with the subjective evaluations of each seat by the 15 subjects. For example, the comment 'too short to support the lumbar area' corresponded with low interface pressures in that part of the spine.

Lee and Ferraiuolo (1993) realised the importance of a large subject base and used 100 subjects in their experiment evaluating 16 visually similar car seats. The seats were fabricated from production ranges by varying the parameters of foam thickness and hardness, back contour and angle, cushion angle, spring suspension rates and side support. Subjects sat in each seat for a minimum of only two minutes and were asked to give a numerical rating (0-10) of perceived comfort in ten body areas . Despite the large number of subjects there were not enough correlations between pressure and subjective comfort for the basis of design decisions. Analysis of the data is being continued.

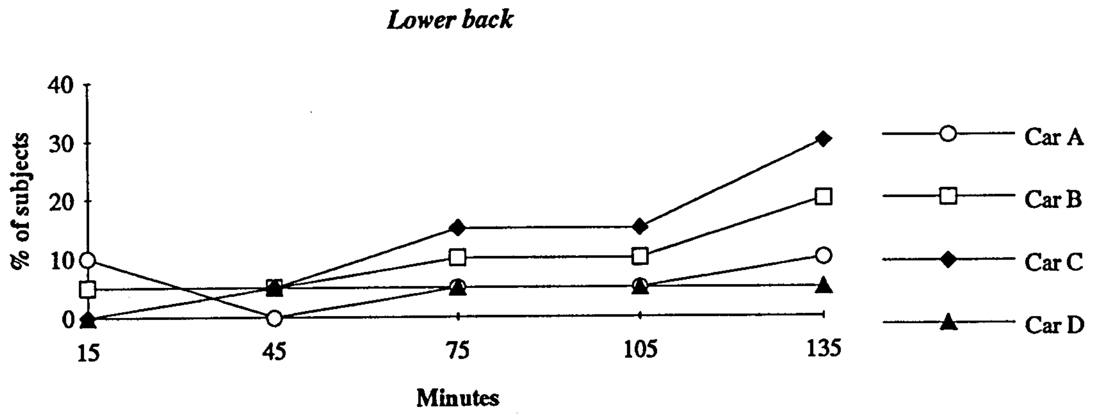
Gross et al (1994) also attempted to correlate the subjective measure of comfort with seat pressure distribution. Likert scales (continuous scale, 1-5 , 'very poor' to 'very good') were used to rate the perceived comfort of 12 aspects of the seat. Data from 50 seats (more than 1100 seat-subject combinations) were collected, each seat trial lasting 5-10 minutes. The authors concluded that the pressure data statistics were strongly related to perceived comfort and therefore perceived comfort could be predicted. However, no details were given regarding the statistical analysis. This paper is mainly criticised for its lack of detail for the more demanding audience for example, the number of subjects was not given; data from only five seats was presented without explanation; the unit of pressure measurement was not given; no information was given on how the overall perceived comfort rating for each seat was calculated and which measures of pressure were used in the correlations. The fact that the relationship between pressure and perceived comfort was only based on 5-10 minute assessment also severely limits its value. Attempts to contact the author were unsuccessful but the lack of detail published may have been due to reasons of commercial confidentiality.

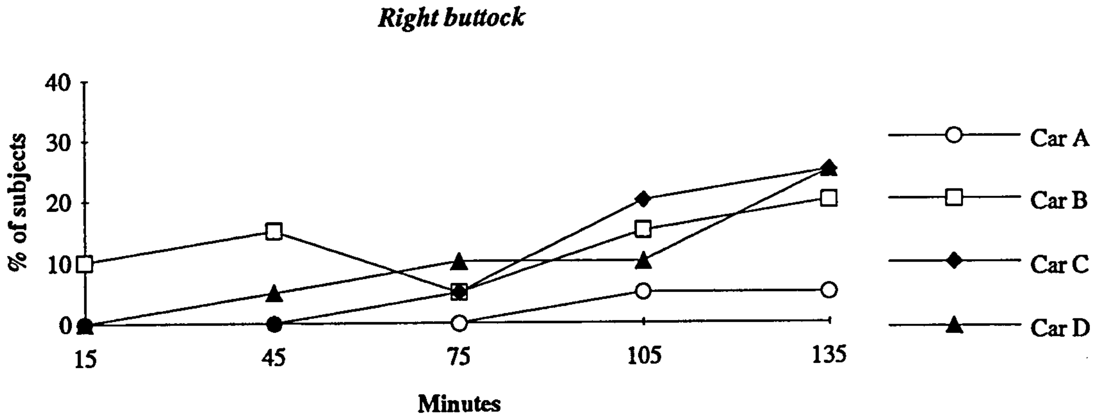
Shen and Galer (1993) attempted to build a multi-factor model of sitting discomfort using interface pressure measurements. Based on their literature review they identified 'the force applied to the body', 'the sitting posture',' the moveability of the body on the seat' and the 'time sitting in a posture' as factors in the model. In their pilot experiment eleven subjects sat in an experimental chair for a 40 minute session. Two seat angles (10 and 20 degrees) and three seat cushion to back rest angles (95, 100 and 105 degrees) were used in a random order to give six postures. Interface pressure measurements were taken and a general comfort rating scale was completed by subjects in each posture. General comfort ratings were not found to be sensitive to the postural differences but pressure measurements did significantly reflect these changes. This study is mainly criticised for the short duration of subjects in each posture (just five minutes), as reported discomfort may vary considerably with time. Also there was no task specified for the subjects to carry out, which could change opinions as to their preferred posture. As Pile (1979) cited in Zacharkow (1988) pointed out, 'what is considered comfortable by a user depends very much on the way a seat is used and how long it is used'.

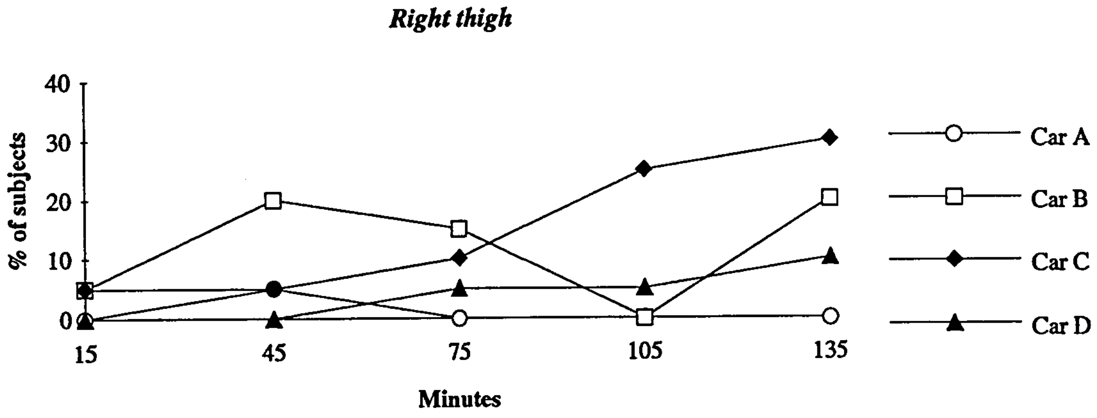
8.5 Rationale for the Experimental Studies

It was felt that the prediction of discomfort should not be based on sitting in a seat for five minutes, but on reported discomfort over a typical period of extended driving. In an unpublished report by Porter and Reed (1992) for the Vehicle Ergonomics Group, the discomfort charts in Figure 25 (from this study) show how Car C was rated as having no discomfort after 15 minutes in the lower back and right buttock. Even after 45 minutes there was no reported discomfort in the right buttock. However Car C was the most uncomfortable after 135 minutes in the lower back and right thigh. As mentioned in Section 8.2.5, the Vehicle Ergonomics Group (VEG) have much experience in assessing driver discomfort. Their road trials always last a minimum of 135 minutes. The necessity of a long road-trial time, is further supported by the fact that in the general public survey most subjects reported discomfort after two hours (refer back to Figure 8, Chapter 5.4.5). It was therefore decided to follow the same time period as the VEG trials. The body part discomfort charts which had been used by VEG for many years and which were found to be sensitive to different driving seat designs and workstations were also adopted for the experiments. They were based on the 'body map' idea of Corlett and Bishop (1976). This saved time and cost in developing and validating a new scale.

Figure 25. The percentage of subjects reporting discomfort in four comparable cars.







It was important to have some control over discomfort so that the objective and subjective methods employed could be explored more systematically. A static, laboratory based experiment would allow a more controlled environment for research and therefore it was necessary to construct a highly adjustable driving rig. This rig would allow the ability to set up a variety of driving postures, so that seating comfort could be studied, by independently changing the seat design and / or the posture. It would also solve the ethical problem of forcing subjects to drive if they were uncomfortable. It was also necessary to specially construct experimental seats to be used with the rig which were identical in fabric, shape, seams, dimensions etc., in order to eliminate any aesthetic factors from analysis of the data. Foam density was the only design parameter which was varied in these experimental seats, and the range was within car seat production limits to simulate real world conditions of soft to hard car seats. The whole emphasis of the experiments was to generate results with real world applicability. For example, it is likely that interface pressure and discomfort would be significantly different if comparing a hard wooden seat and a soft foam over a medium term driving trial, but this information is not of practical use to car seat manufacturers.

There were high hopes in the automotive industry that interface pressure measurement could be used to predict areas of discomfort in a car seat. With regard to interface pressure studies it seemed that so far any conclusions from such studies were contradictory. Few studies attempted to correlate discomfort with pressure and the duration of the trials was usually only 5, 10 or 15 minutes. However, simple relationships had already been established between pressure and body type, pressure and gender, pressure and seat hardness and pressure and posture under controlled experimental conditions. It was therefore decided to focus on the technique of interface pressure measurement and to carry out a series of experiments to explore the results of its practical application. These experiments were as follows:-

Experiment 1.

Investigation of the optimum driving posture and positions of the main driving controls (n=56). The postural angles for comfort recommended by both Rebiffe (1969) and Grandjean (1980) were based on theoretical calculations (Chapter 2.3.5) and not observed driving postures. Data regarding the observed, preferred driving posture for comparison with these theoretical postures were required, to further aid the design of the car workstation. Reed et al (1991) also advocated a need for this.

Experiment 2.

Investigation of predictors of discomfort using a static (n=14), repeated measures design. Each subject's optimum driving posture would be determined and maintained for their preferred and least preferred seats (within a production range of foams) for two separate 2.5 hour driving simulations. The experiments could have been set up to look for differences between the hardest and softest seats, but they both could have been uncomfortable. Subjects should represent a wide range of sizes. Preferred and least preferred seats should be selected by the method of paired comparisons.

Experiment 3.

Investigation of predictors of discomfort using a static (n=12), repeated measures design. The seat that was judged to be the most comfortable (of the seven available) by subjects in Experiment 2 would be used in this experiment. This seat would be the constant and carefully selected subjects, different to Experiment 2, would sit in both a limited (taken from a well known car) and a fully adjustable driving package for the same 2.5 hour static, driving simulation (n=12). In this way posture would be varied but within realistic constraints for driving. Subjects should represent the extremes of anthropometric data (tall males and short females being the ones most likely to have problems with existing driving workstation design).

Experiment 4. (Future Work)

Investigation of predictors of discomfort using a dynamic (n=18) repeated measures design. Dynamic discomfort data have already been collected from 2.5 hour road trials of three different cars. Subjects were selected to represent a wide range of sizes. Interface pressure and posture data would be then collected from the same subjects for comparison with the dynamic discomfort data.

N.B. This experiment was completed but does not form part of this PhD thesis.

The following methods were finally selected, within the constraints imposed by cost, time available and their practicality for exploration in the above experiments:-

Objective methods:-	Interface pressure measurement.
	Posture analysis (using a goniometer).
	Anthropometric data.
Subjective methods:-	Body part comfort / discomfort charts.
	Seat Feature Checklist.
	The method of paired comparisons.
	Predictive seat detail questionnaire.
	The method of fitting trials.

Chapter 9. Development of the Equipment

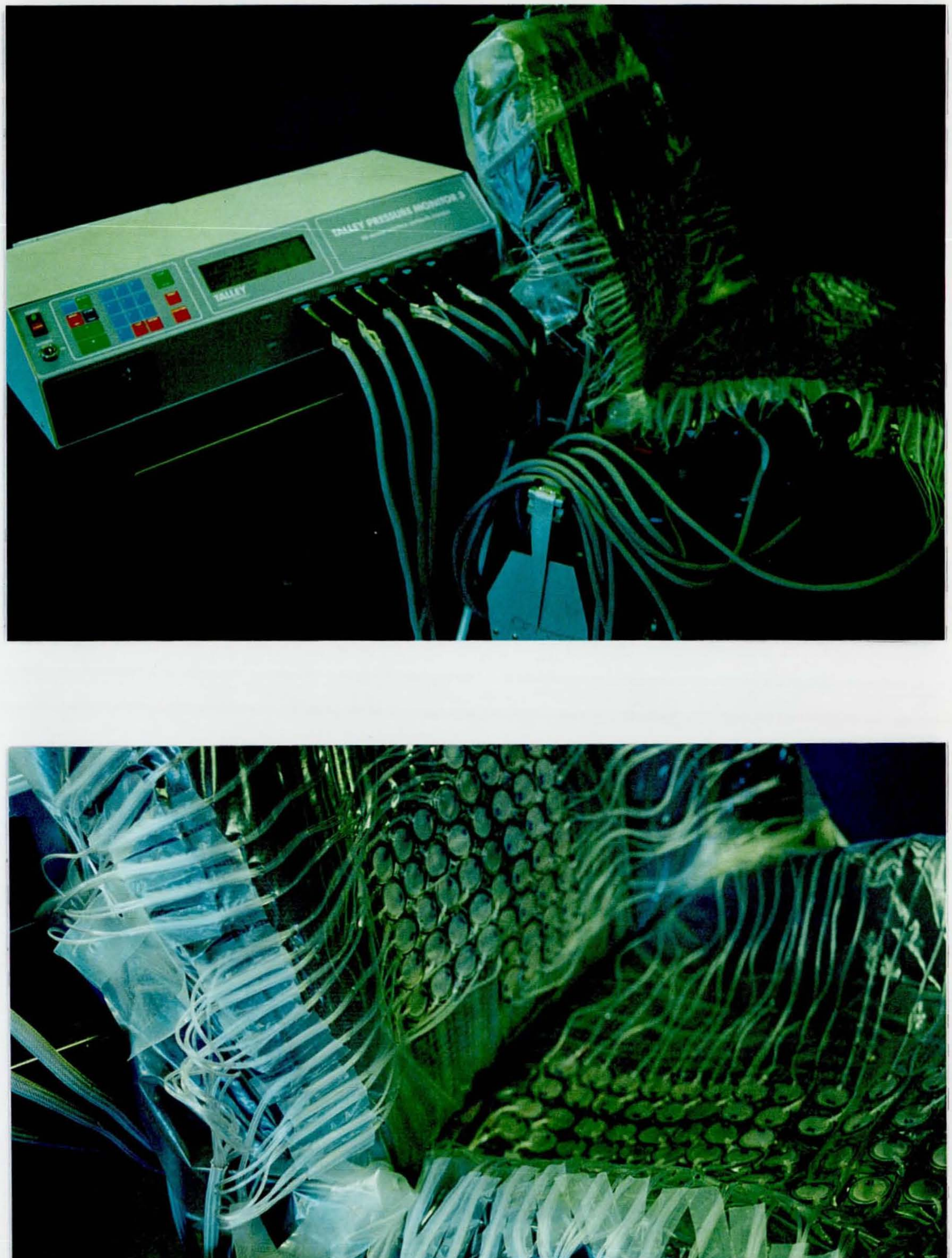
9.1 Introduction

Following the review of the literature it was decided to concentrate on the objective method of interface pressure measurement as a predictive technique for comparison with subjective measures. The Talley Pressure Monitor (TPM) was already available for use, although some refining of the cell matrix and the data obtained was required. The following sections describe the development of the equipment for car seat pressure measurement, the driving rig and the experimental seats.

9.2 The Talley Pressure Monitor Mark 3 (TPM)

The pros and cons of different pressure measurement technologies were discussed in Chapter 8.4.4. The TPM is a pneumatic system (Figure 26) and in a comparative evaluation by Ferguson-Pell and Cardi (1991), it produced the most accurate and repeatable measurements but was limited by scan rate and ease of use. It was also considerably cheaper than other commercially available models. Giacomin (1995), in tests at the Fiat Research Centre (Turin) also found that the TPM compared favourably with other technologies currently available. It scored highly for repeatability, measurement drift, thermal drift, fatigue resistance, calibration and cost against four other commercially available systems but negative points were the large size of the sensor and the fact that it could only be used for static measurements. The system which performed the best in the tests at Fiat cost ten times more than the TPM.

Figure 26. The Talley Pressure Monitor (TPM) Mark III and cell matrix.



9.2.1 Development of the Talley Pressure Monitor (TPM) Cell Layout

It became obvious from exploratory work with the TPM that there were problems with the existing product for use with car seats and these had to be addressed to obtain the highest quality possible interface pressure measurements. The existing matrix needed to be adapted to provide cell coverage for the important areas of the seat cushion and seat back, its durability needed improvement and better understanding of the performance of the cells was required. The main problems were as follows:-

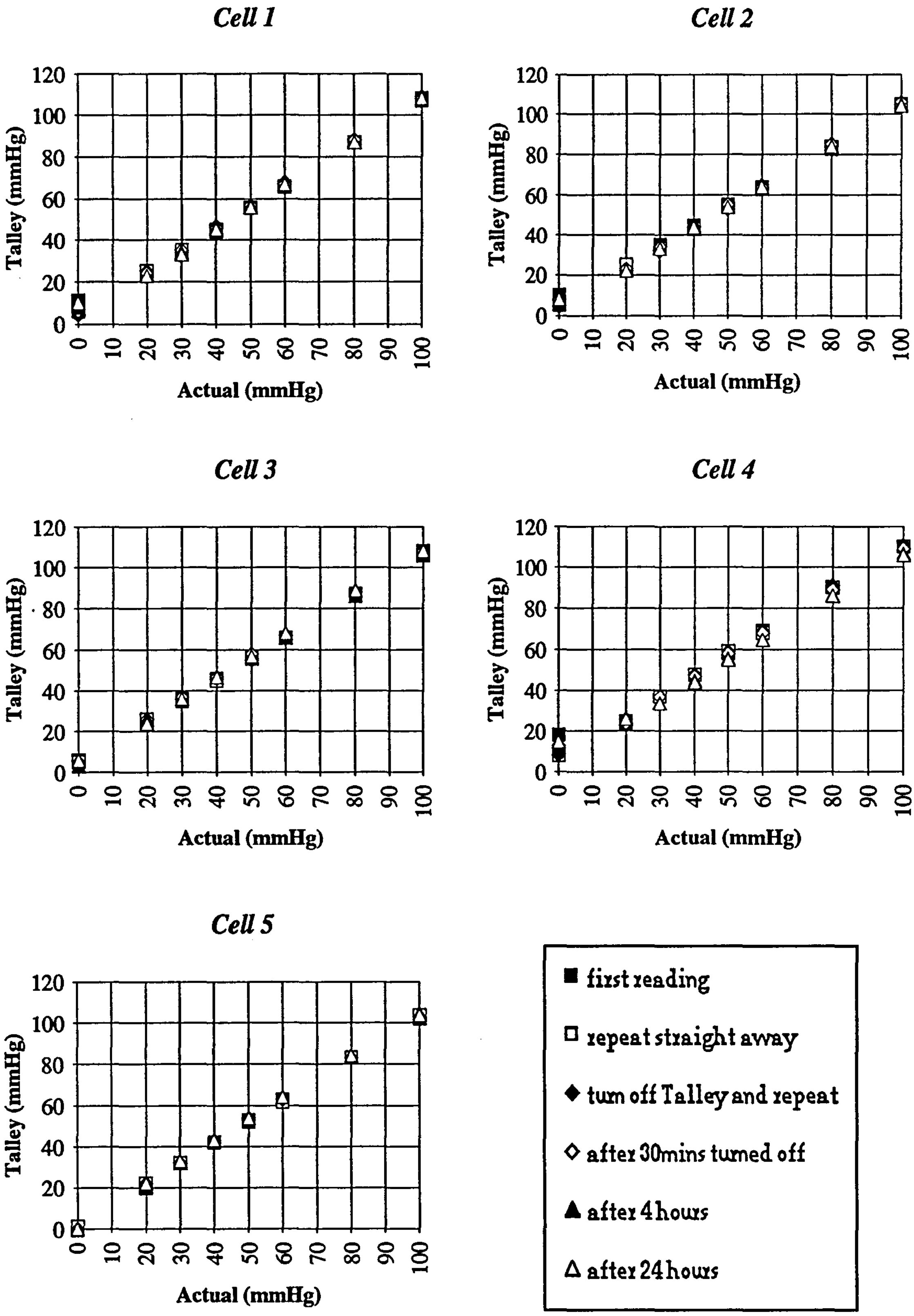
1. The diameter of the individual cells was 20 mm; a maximum of 14 mm was recommended by Ferguson-Pell (1980) for measuring peak pressures. The resolution of the cells was also poor with as much as 100 mm between cell centres. Also only 48 cells were allowed for each matrix to cover an area 330 x 330 mm. With this arrangement it is highly probable that the peak pressures under the Ischial Tuberosities (IT's) could be missed.
2. The cell matrix was impractical to use; cells were 'floating' in pockets and were prone to twisting and folding. The backing material was also easily stretched and damaged and did not support the weight of the cells and cables adequately.
3. The technical specification of the TPM matrix was not in sufficient detail to understand the performance of the cells. A series of exploratory experiments looking at the effects on the cells of stretch, curvature, partial coverage, battery versus mains and repeatability were required to improve reliability and validity of the interface pressure measurements. These experiments would also provide information for the most appropriate layout of the cells.
4. It had been noticed that certain cells produced large inaccuracies in the readings. An improved method of error correction and calibration was required.
5. If the positions of the cells on the matrix were altered, new mapping procedure software was necessary.

9.2.2 Exploratory Experiments using the TPM

Repeatability of interface pressure readings over time and calibration

Twelve individual new cells were tested for accuracy from 0-100 mmHg by placing the cells in the calibration bag at known pressures and noting the readings over six time periods. Typical examples of these are shown in Figure 27.

Figure 27. Pressure readings over time.



TPM pressure readings were shown to have a linear relationship with actual pressure, which is reasonably constant over 30 hours. It also appears that a 'rogue' cell is consistently a 'rogue' cell over a 30 hour period at zero and then joins other cells in accuracy between 60-100 mmHg. These facts allowed a method of error correction to be developed whereby two calibration readings were taken of the cells in a flat calibration bag at 60 mmHg and 100 mmHg (the levels recommended by the manufacturers). Using these individual cell values and the equation $y=mx+c$, the gradient and intercept could be calculated. Any TPM interface pressure reading could then be corrected by putting x (the TPM reading) into the equation and getting out y (the actual pressure reading). These calibration readings were to be taken every 2-3 days.

N.B. The method of calibration suggested by the manufacturer must also be carried out to obtain an accuracy of + / - 5 mmHg.

The effects of partial coverage of the cells on TPM accuracy

It was necessary to know the effect of a pressure point only partially covering a cell on the accuracy of the interface pressure readings. A cell was set up in a vice between two pieces of high density foam in order to obtain a constant pressure. Three readings were taken with each of 100% cell coverage, 75% coverage and 50% coverage. This experiment was repeated with three other cells. Figure 28 shows the results of the average of the three readings for a typical cell. Assuming the base reading (whole cell coverage) was the true pressure, the inaccuracy at 50% cell coverage was unacceptable. For example 100 mmHg actual pressure was read as 82 mmHg at 75% coverage and 11 mmHg at 50% cell coverage. It was therefore deduced that cells on the matrix should be arranged in as high a density as possible to obtain the best accuracy for peak pressures.

The effects of cell curvature on TPM accuracy

It was important to know the effects of a curved interface on the cell readings, because car seat design often involves intricate shaping and curved surfaces. Two cells were loosely taped around cylinders of varying radii, to obtain a range of cell curvatures. Pressure readings were then taken at 0 mmHg and 20 mmHg. Due to limitations in the strength of the original calibration box it was not possible to increase pressures further, without damaging the device. Figure 29 shows that inaccuracies in readings increase rapidly with a radius of below 45 mm, as could be the case with the join of the lateral supports or curvature in the front of the seat cushion for example. The mechanism of the TPM is such that cell curvature requires higher pressures to fill the cell with air.

Care must therefore be taken with any readings where the cells cover any sharply curved seat shaping.

Similarly, folding of the cell lead to gross inaccuracies (readings of 246 mmHg) for pressures of 0-100 mmHg. Blocking the cells air exit / entrance reduces air volume giving a high reading. This has implications that care should be taken that cells on the matrix are not twisted or folded.

The effect of cell stretch on TPM accuracy

If the cell matrix was placed over a car seat, the cells may be subjected to some stretch. To obtain information on the behaviour of cells under such conditions, three individual cells were stretched to excessive diameters using a pulley and spring mechanism and pressure readings were taken at 0 mmHg, 20 mmHg and 100 mmHg (Figure 30). The cells tolerance to uni-dimensional stretch was good and therefore no problem was posed.

Battery versus mains supply

The TPM is supplied with a 12v sealed lead acid battery which runs for approximately 3.2 hours fully charged. During experimentation it is often necessary to use the TPM for a much longer period, hence the need for a mains option. The maximum, minimum and mean readings of 12 cells were taken and repeated 10 times with each of the battery and mains power supplies at pressures 0, 20 and 100 mmHg. The student t-test was used to compare the effects of the power supplies, but there was no difference between groups for either the maximum, minimum or mean values. It can therefore be concluded that there is no significant difference between readings taken using the battery and those using the mains supply.

Figure 28. The effect of partial cell coverage on TPM accuracy.

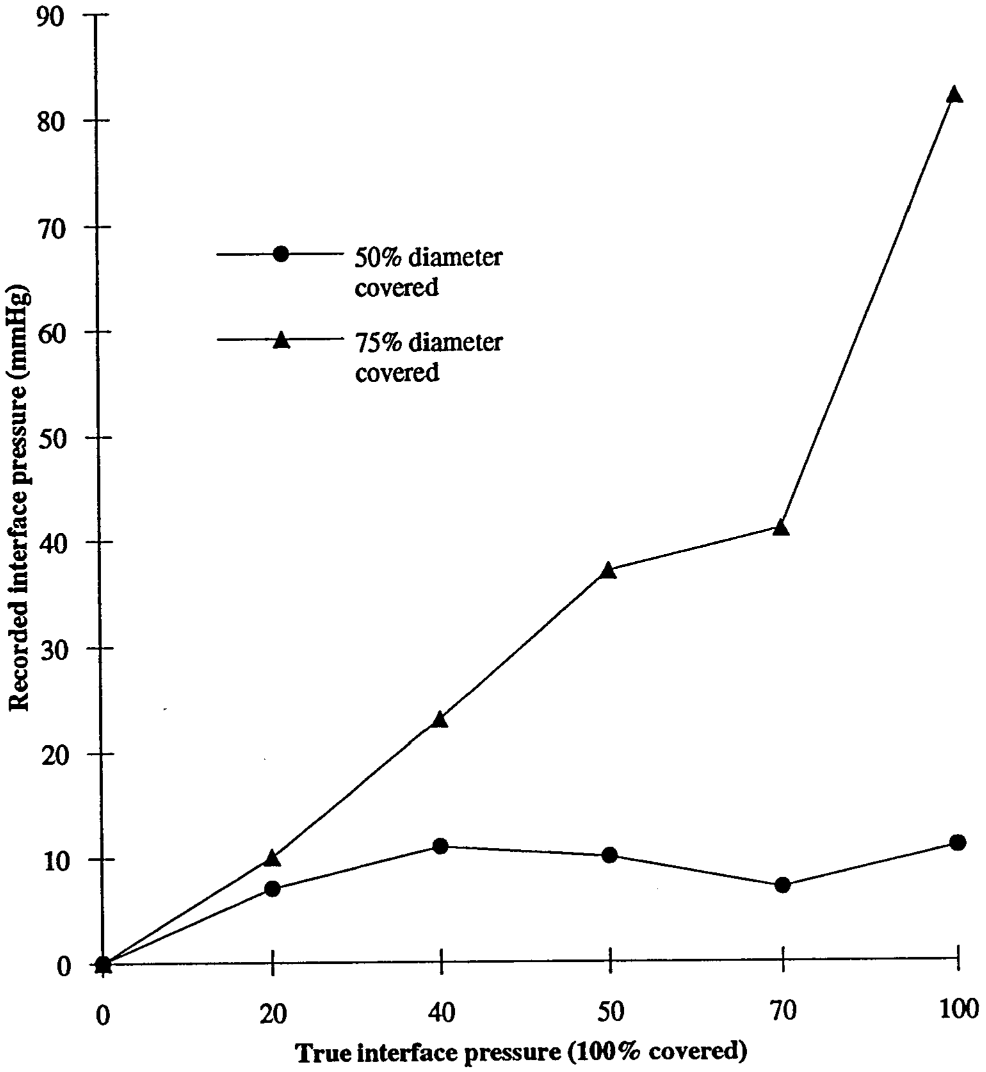


Figure 29. The effect of interface curvature on accuracy at low pressures.

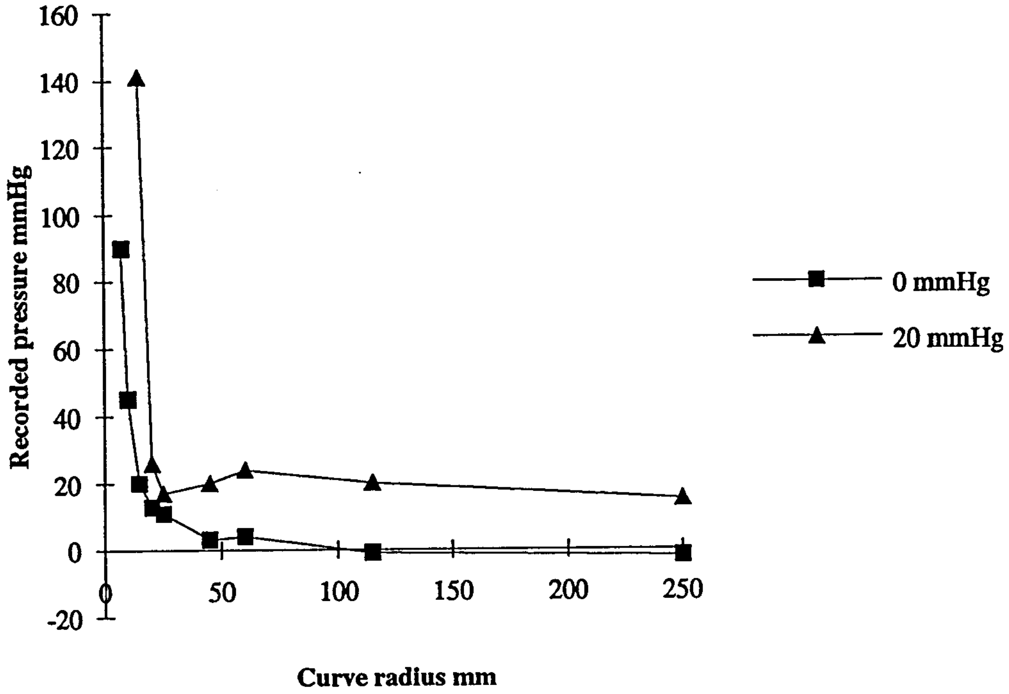
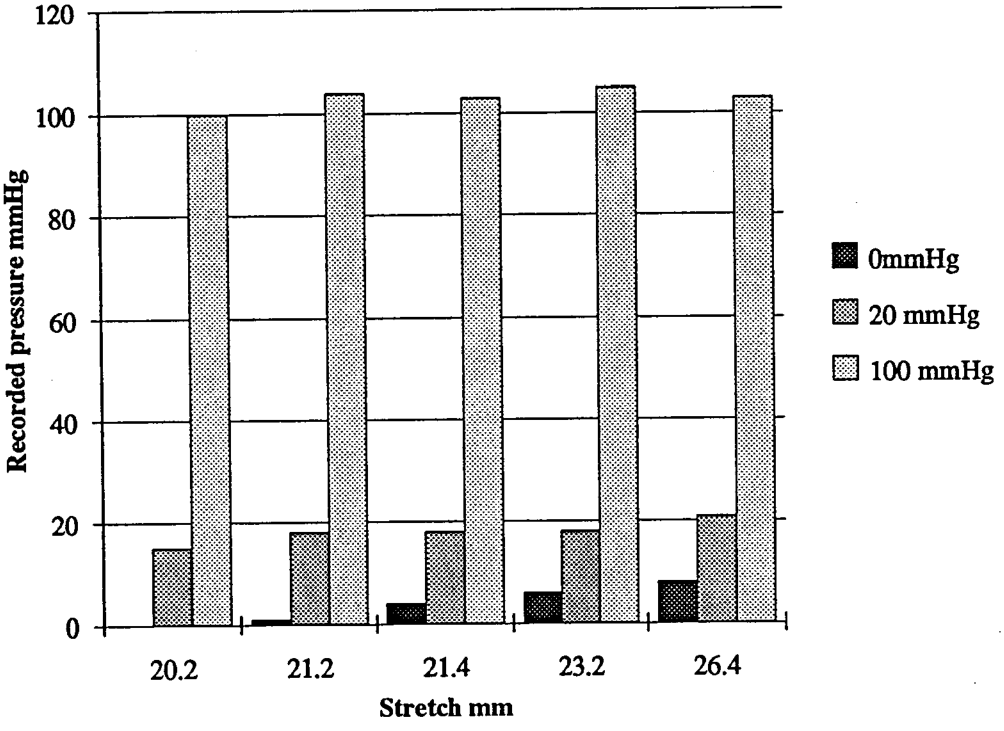


Figure 30. The effect of cell stretch on TPM accuracy.



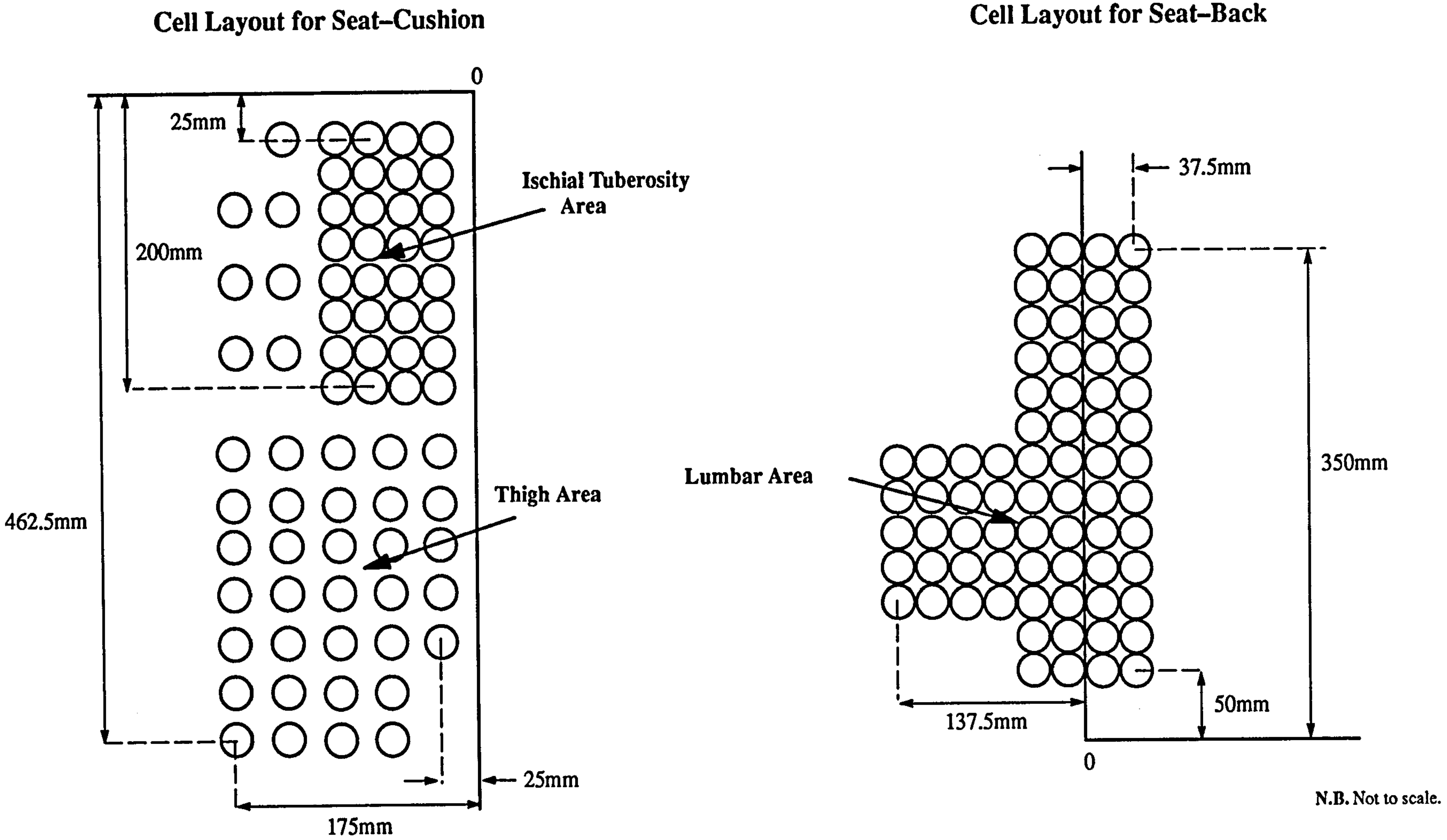
9.2.3 Re-design of the TPM Cell Matrix

The cell diameter of 20 mm could not be altered, therefore a high cell resolution was of vital importance to improve accuracy in interface pressure readings. It was also known that care must be taken in interpreting readings at the seams or edge of the seat. Due to costs and practicalities, only 144 cells were available for the seat cushion and backrest (72 cells for each - six data channels). A decision was therefore taken to design a half matrix to measure pressure under the right side of the body. Observation of earlier data showed little asymmetry in seated pressure maps of normal individuals in the laboratory. Many other authors' investigations support this view (Bush, 1969; Drummond et al, 1982; Congleton et al, 1988 and Eckrich and Patterson, 1991) and even if there was asymmetry, car seat designers may not be able to address this.

Figure 31 shows the new cell matrix layout. The seat cushion matrix was designed to have high resolution in the region of the Ischial Tuberosities (23 mm spacing between cell centres) and lower resolution towards the thighs (37.5 mm spacing). The backrest was designed to have high resolution along the spinal cord and sacrum out to the superior iliac crest (23 mm spacing). Zacharkow (1988) recommended pelvic-sacral support just below the highest part of the superior iliac crests in order to provide support to the upper sacrum, pelvis and lower lumbar spine. Data from and Herzberg (1972) was used a reference for the anatomical dimensions of the Ischial Tuberosities and Branton (1984) for the spine, both summarised in Table 48.

Table 48. Summary values for spinal and Ischial Tuberosity (IT) landmarks (Herzberg, 1972 and Branton, 1984).

Dimensions (mm)	Mean (Standard Deviation)
Seat back to rear of buttock	20 (10)
Rear of buttock to rear of IT area	71 (18)
Depth of IT area	36 (13)
Lateral edge of buttock to IT area	89 (28)
Breadth of IT area	36 (13)
Distance between medial edges of the IT areas	61 (13)
Computed distance between IT centres	97 (13)
Centre of lumbar curve height above the seat	182 (118)
Centre of the sacrum above the seat	159 (22)


Cell Layout for Seat–Cushion

Cell Layout for Seat–Back

Figure 31. Modified cell layout for the seat cushion and seat back.

A more resilient backing material was required to mount the cells. Ideally this material needed to be thin and flexible with minimal interference between the seat-buttocks interface. The material should also feel comfortable against the skin and have frictional properties to prevent the subject sliding off the seat without sticking to clothes and creasing. Samples of polymers were judged against the above criteria and eventually a slightly thicker version of the original backing material (a Polyether urethane based Polymer) was chosen. New cells were secured to the backing material using double-sided tape in the new layout, after checking that the pressure readings were not adversely affected by the adhesive tape. The cables were then carefully routed to avoid kinks.

9.2.4 Mapping Procedure Software

A C-program (Kernighan and Richie, 1988) was written at the university to aid the processing of pressure readings into a suitable presentation format. All stores of data were downloaded in the form of a text file via the TPM's serial interface. Program 1 divided the original data file into separate files for each store number. Program 2 divided each store and used a pre-written reference file to link the cell number and pressure to an arbitrary co-ordinate system. The pressure reading for each cell was also corrected by reading the files containing the calibration data (at 60 mmHg and 100 mmHg), calculating the gradient and intercept for each cell and then using the equation $y=mx+c$ to obtain the error corrected pressure value for each cell. Program 3 used the text file produced by program 2, to produce interface pressure maps in various formats for example 2D dot, 2D line and 2D contour (Appendix 7) in the UNIMAP software. A bilinear, quadratic interpolation method was carried out by the UNIMAP software to achieve smoothing of the 2D line and 2D contour maps. Finally program 4 produced a command file to load the UNIMAP saved file and then produce a PostScript file for printing.

9.2.5 Calculation of Interface Pressure Variables

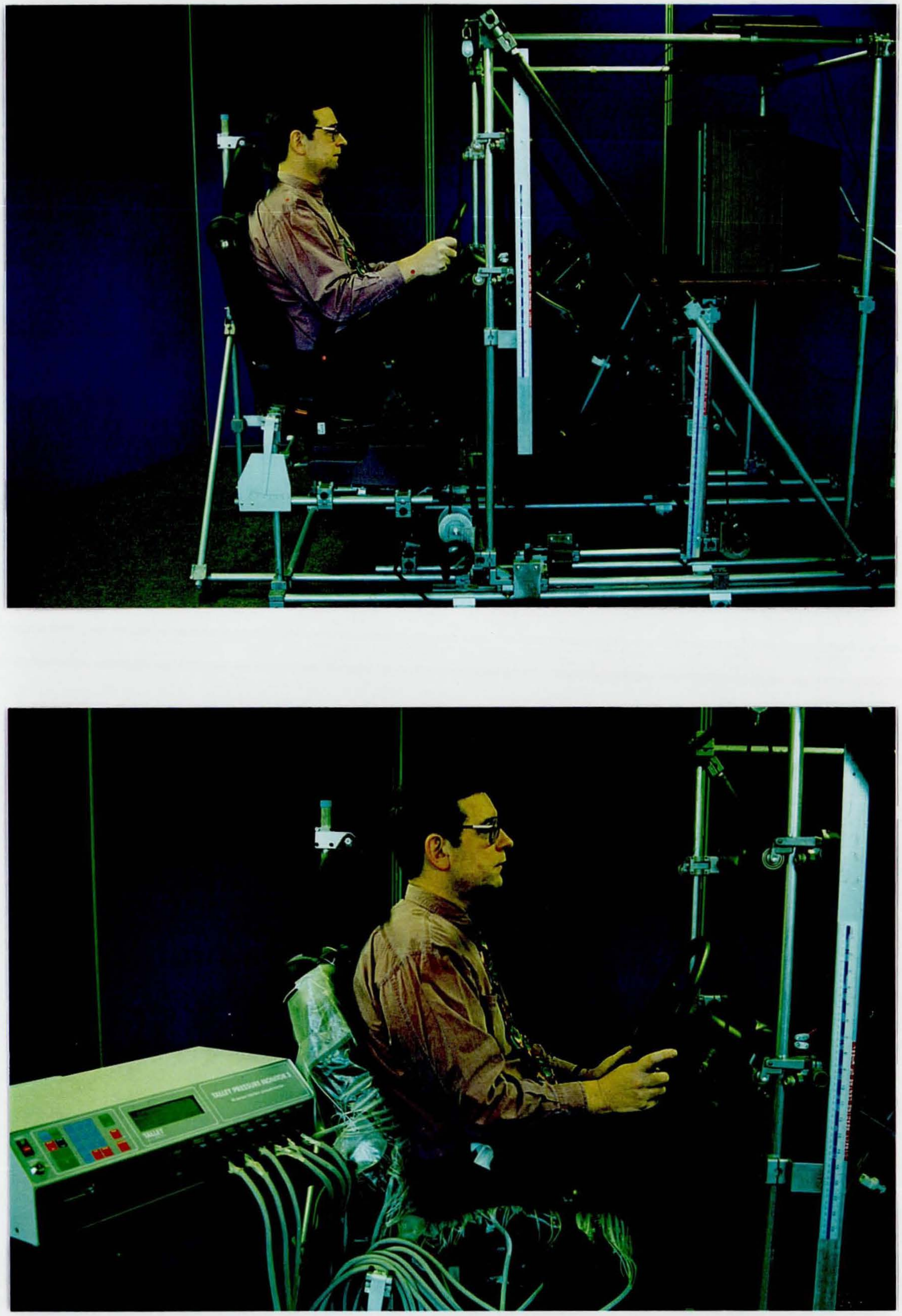
The literature was not helpful with detail concerning the analysis of interface pressure maps. It was therefore necessary to design a methodology for quantifying the data collected. Individual raw TPM data were visually inspected to locate the IT, thigh and lumbar area. Obvious errors in the data were removed and given values in line with adjacent cells. By observation of data collected from pilot trials and discussion with colleagues it was decided that nine cells (36 square cm) were required to 'capture' the high pressures under the IT's. This area was judged to be the nine cells of high pressure values located in the position of the IT for each individual. Taking into account buttock-knee length and body position, eight cells (32 square cm) were located to represent pressure in the central thigh area. The pressure plots revealed no obvious lumbar area therefore the number of cells in contact with the low back was taken to be the area of support in the low back. All judgements were checked by a second experimenter. Once the cells were selected, interface pressure variables for example mean and standard deviation were calculated (Appendix 8) and these were entered onto a spreadsheet. It was not known at this stage which variables would provide useful information. This method was very time consuming but there was no alternative with no affordable quantification software available at the time.

9.3 Development of the Driving Rig

A highly adjustable driving rig was required as explained in Chapter 8.5. It was constructed in the laboratory by a university engineer, under the direction of the author (Figure 32). Criteria for its construction were the following:-

1. A wide ranges of sizes of subjects (1st percentile females to 99th percentile males) could be accommodated in either extremely flexed or extended driving postures. A CAD man-modelling system called SAMMIE was used to aid these calculations. For more details of this system the reader should refer to Porter et al (1993).
2. The steering wheel and pedals were easily fully adjustable to ranges in order to satisfy the above, within the constraints of the design.
3. The positions of the controls could be easily measured from a fixed reference point and converted to H-point values (SAE Handbook, 1985).
4. The workstation i.e. the floor, steering wheel and pedals, would be adjustable around the seat. The seat itself was also adjustable in tilt, backrest angle and lumbar support.
5. The pedals, gearbox and steering wheel were operational (incorporating some realistic force) to allow subjects to mimic the movements of driving, whilst watching a driving video.
6. It was necessary that the different seats could be replaced quickly and easily between experiments.
7. Cost, time and materials constraints as governed by the Brite Euram Project.

Figure 32. The Experimental Driving Rig.



9.3.1 Development of the Driving Rig Video

Attempts to find a suitable video which would keep interest but not be too boring or too exciting (i.e. a video game) for use with the rig proved futile. It was therefore decided to make two videos of the 2.5 hour test route used regularly by the Vehicle Ergonomics Group in their road trials, with a voice-over of instructions about the route to guide the driver. The video gave a driver's view of the road through a car windscreen of the 60 mile test route. It encompassed a range of road types including motorways, country roads and town driving for the simulation of driving tasks and allowed the maintenance of a realistic driving posture. Early trials using the video with the rig helped to determine the best style of verbal instruction. The video also included a stopping-point every 30 minutes for subjects to complete comfort / discomfort charts.

Table 49. Detail regarding the seat foams in the experimental seats.

Seat Number	Seat Description	Seat Cushion Hardness (daN)	Backrest Hardness (daN)
1	Hard seat cushion & backrest.	48.4	36.6
2	Reference backrest & seat cushion back, with hard seat cushion front.	36.0 & 50.0	18.0
3	Reference backrest & seat cushion back, with soft seat cushion front.	37.0 & 20.0	18.0
4	Medium soft seat cushion and backrest.	32	17
5	Soft seat cushion & medium soft backrest.	27.2	17.2
6	Medium hard seat cushion & backrest.	42.8	25.2
7	Reference seat cushion & backrest.	38.6	18.0

N.B. daN=deka Newtons.

9.3.2 The Experimental Seats

Seven experimental seats were specially constructed by Sepi SpA, Turin, for use with the rig to cover a range of hard and soft production foams. The seats were identical in profile and outward appearance but varied in foam hardness (within the typical production range) and were based on the design of the Fiat Tipo C. A description of the seven seats is given in Table 49. Seat 7, the 'reference seat' is the actual production Fiat Tipo C.

9.4 Summary

As a result of exploratory work, the TPM matrix was re-designed to obtain the optimum quality interface pressure data from car seats using this system. The calibration technique was modified for improved accuracy and software called UNIMAP was used to display the data in a variety of formats. A methodology for quantifying the pressure data was also established.

The fully adjustable driving rig with interchangeable experimental seats also was constructed for use with a video of the Vehicle Ergonomics Group 2.5 hour test route. Subjects could then mimic the actions of driving during the planned driving trial experiments.

Chapter 10 Experiment 1- Optimum Driving Postures and the Positions of Controls

10.1 Aims

The main aim of this study was to collect data regarding the optimum postures which subjects would adopt given a fully adjustable driving package. Despite the theoretical work of Rebiffe (1969) and Grandjean (1980) described in Chapter 2.3.5, there is a need for more data regarding the actual joint angles individuals adopt in the driving situation and also the interrelations between these angles. This study will also provide car manufacturers with information regarding the ranges of adjustment of components of the car workstation for example the steering wheel, necessary to satisfy these preferred postures.

10.2 Experimental Procedure

Subject selection

Subjects were all paid volunteers selected from members of the general public who responded to an advertisement in the local paper. They were carefully selected to include a wide range of percentiles (calculated from Pheasant, 1990b) for the dimensions important for car workstation design and to be representative of the car driving population in Western Europe (Appendix 9). Other criteria for their acceptance into the study were that they were drivers (one year minimum), they had suffered no musculoskeletal troubles during the last year and they covered a wide range of ages under 65 years. They were instructed to wear clothing which was not too bulky (for ease of the pressure and posture measurements), but which was comfortable for driving. They were also asked to wear shoes which they would normally wear for driving.

Equipment and laboratory

Experiments were conducted using the experimental rig as described previously in Chapter 9.3, fitted with seat 4. This car seat was shown to be the best overall in the pilot trial from the method of paired comparisons (Chapter 8.2.3) and would minimise the confounding effect of discomfort from the seat itself. If the seat was too hard at the front of the cushion, the subject would be constrained by the need to sit closer to the pedals than preferred, in order to minimise the effect of the hardness under the thighs. Lighting, temperature and ventilation were all held constant in the laboratory.

The Fitting Trials

The experimental protocol for each one hour session was identical and had been passed by the Ethical Advisory Committee (LUT). Subjects were given a brief introduction to the study and those anthropometric measurements most relevant to car seating were taken; stature, sitting height, buttock-knee length, knee height, hip breadth and arm length. The method of fitting trials, described in Chapter 8.2.4 was then carried out to obtain the optimum height and distance away from the body of the steering wheel, height of the car floor, distance from the body of the pedals and tilt of the seat. For each of these adjustments the component was moved by the experimenter at discrete increments throughout its range of travel from one extreme to the other and back again, balancing the order of this. When a satisfactory position was reached, it was fixed. Following adjustment of all the controls the positions were fine tuned until satisfactory. A 10-15 minute driving simulation at the rig was then carried out to further confirm that this posture was optimum and then relevant measures regarding the positions of the controls from a fixed reference point were documented. Calculations were then carried out to convert these to the H-point values shown in Figure 33 .

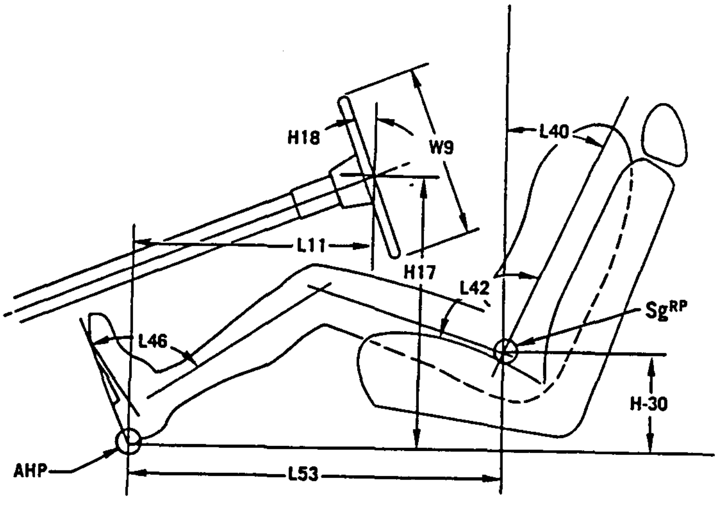


Figure 33. Vehicle Seating Configuration (SAE Handbook, 1985).

The subject was then asked to 'freeze' in their driving posture, semi-depressing the accelerator, placing the hands on the steering wheel (if appropriate) and looking ahead as though they were driving on a road. Joint markers had already been positioned on the anatomical landmarks (C7, acromium, lateral epicondyle, ulnar styloid, greater trochanter, lateral condyle and lateral malleolus) to aid the measurement through clothing (Figure 34). The positions of the joint markers were checked and then postural angles were then measured on the subjects right hand side with a goniometer. Each angle was measured three times and the average value taken.

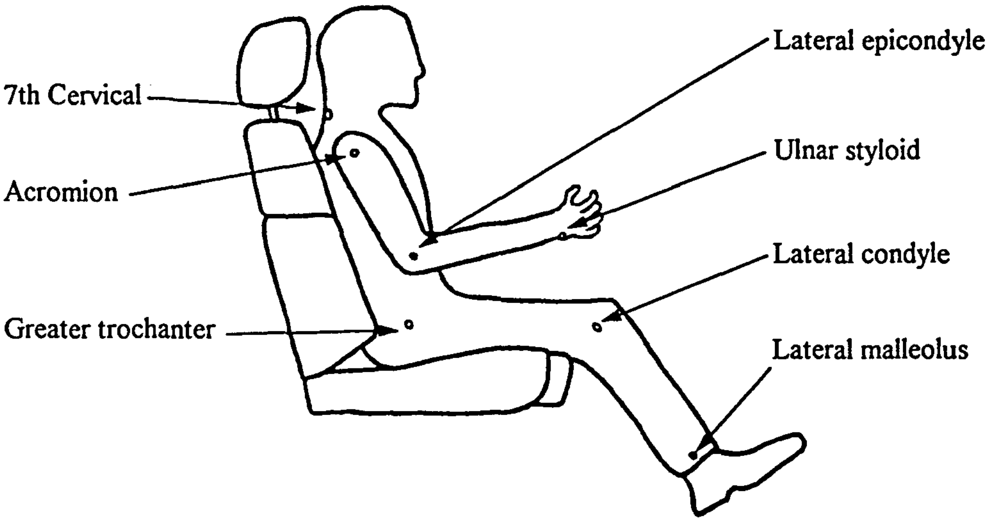


Figure 34. The positioning of the joint markers.

The postural angles were defined as follows for use in these experiments, adapted from Grandjean et al (1983), Bridger (1988) and Bhatnager et al (1985):-

1. Neck inclination: The angle between the vertical and a line from the 7th cervical vertebrae to the auditory canal.
2. Trunk-thigh angle: The angle between a line from the acromium to the greater trochanter and a line from the lateral condyle to the greater trochanter.
3. Arm flexion: The angle between the vertical and a line from the acromium to the lateral epicondyle.
4. Elbow angle: The angle between a line from the acromium to the lateral epicondyle and a line from the ulnar styloid to the lateral epicondyle.
5. Knee angle: The angle between a line from the greater trochanter to the lateral condyle and a line from the lateral malleolus and the lateral condyle.
6. Ankle angle: The angle between a line from the lateral condyle to the lateral malleolus and a line parallel with the foot.

A Seat Feature Checklist was also administered to obtain subjective opinions regarding the seat (Appendix 10).

10.3 Experiment 1 Results

10.3.1 Summary Statistics for Experiment 1

Age

The age distribution of the sample is described by gender in Table 50 below.

Table 50. The age distribution of the sample in Experiment 1 by gender.

	Mean (SD)	**Age Range**
Whole sample (n=56)	41.7 (13.1)	20-63
Males (n=28)	41.5 (14.2)	20-63
Females (n=28)	41.9 (12.2)	21-63

Postural angles

Actual observed postures were compared with recommendations from the literature as shown in Table 51. All the postural angles data for one female subject were removed from the sample as she was felt to have an unusually large neck lordosis (neck inclination 91 degrees), and consequently had a pronounced kyphosis of the upper back, confounding the measurement of postural angles using the anatomical landmarks.

Table 51. Comparison of observed postural angles for comfort (in degrees) with the literature.

	Rebiffe (1969)	**Grandjean (1980)**	**Observed Postures (n=55)**	**95% Confidence Limits**
Neck inclination	20-30	20-25	30-66	29-63
Trunk-thigh angle	95-120	100-120	90-115	89-112
Knee angle	95-135	110-130	99-138	103-136
Arm Flexion	10-45	20-40	19-75	16-74
Elbow angle	80-120	-	86-164	80-161
Foot-calf angle	90-110	90-110	80-113	81-105
Wrist Angle	170-190	-	-	-

Females generally preferred a more upright and flexed driving posture than males as indicated by lower mean arm flexion, elbow angle, knee angle and trunk-thigh angle (Table 52).

Table 52. Preferred posture (in degrees) by gender in Experiment 1 (n=55).

	Males (n=28) **Mean (SD)**	**Females (n=27)** **Mean (SD)**	**Significance of t**
Neck inclination	47.4 (8)	44 (8.5)	NS
Trunk-thigh angle	101 (6)	99 (5.2)	a
Knee angle	121 (8.1)	117 (8.6)	NS
Arms Flexion	50 (2.4)	40 (2.8)	**
Elbow angle	128 (20.3)	113 (17)	**
Foot-calf angle	93 (6.4)	92 (5.3)	NS

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001

Positions of the controls

The subjects preferred positions of the controls were recorded from the driving rig and converted to H-point values (SAE Handbook, 1985). These values were directly compared with actual vehicle dimensions from a sample of 32 well known cars (Appendix 11).

Seat Feature Checklist

The Seat Feature Checklist was used to gauge initial impressions of the seat. The results for subjects who participated in Experiment 1 only (n=42) are shown in Appendix 12. The results of subjects who went on to complete Experiment 2 are given separately in Chapter 11.4.1, as they completed this questionnaire prior to their medium term drive in the rig. Generally subjects were happy with the seat height adjustment offered by the driving rig, however 81% of males and 43% of females would have preferred the seat cushion to be longer and 43% of males and 24% of females would have preferred the seat cushion to be wider.

Subjects were generally happy with the seat back and the lumbar support, although 38% of subjects adjusted the lumbar support to its minimum position. The majority (61%) used the lumbar support on considerably less than its maximum setting (approximately one fifth), with only one subject using the maximum setting.

10.3.2 Interrelations Between Anthropometry, Posture and the Positions of the Controls

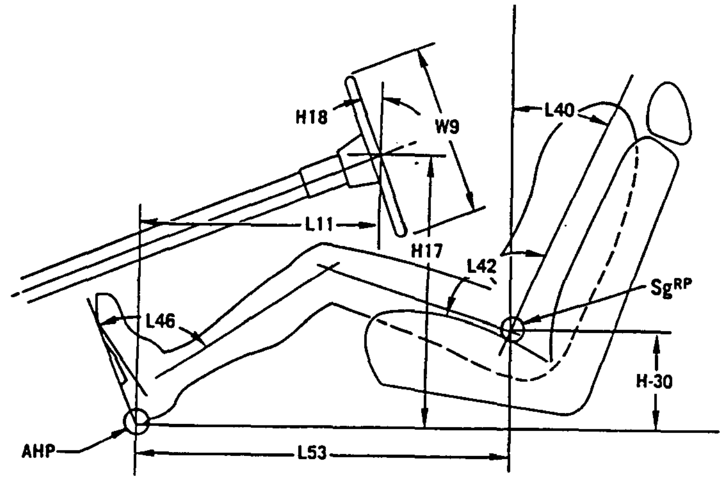
Anthropometry and the positions of controls

The distance of the steering wheel from the subject (L53-L11) significantly positively correlated with all measured anthropometric dimensions, for males and females (apart from knee height), larger subjects preferring the steering wheel further away from the body (Table 53). The height of the steering wheel from the body (H17-H30) for females only, also significantly positively correlated with all anthropometric dimensions measured, larger females preferring the steering wheel higher. Males with larger stature and sitting height also preferred the steering wheel higher in relation to the body. Stockier females, as implied by larger hip breadths and weights, also appeared to sit more upright, as shown by significant negative correlations between hip breadth and weight with seat angle (L40) and seat back angle (L42).

Table 53. Correlation coefficients (Pearson's r) for steering wheel position and anthropometric measurements (males and females).

	Males (n=28)				**Females (n=27)**			
	L53-L11	**H17-H30**	**L40**	**L42**	**L53-L11**	**H17-H30**	**L40**	**L42**
Stature	.5653 **	.3737 *	-.1787	-.0119	.5437 **	.4769 **	-.0958	-.0520
Weight	.3801 *	.0010	-.0959	.0855	.6385 ***	.5681 **	-.5056 **	-.4322 *
Sitting height	.5259 **	.4214 *	-.2701	-.1237	.4749 **	.3180 a	-.1811	-.0486
Buttock knee length	.5557 **	.2554	-.1353	.0823	.5722 ***	.6270 ***	-.2934	-.2521
Knee height	.5636 **	.2173	-.1743	-.0243	.2344	.4863 **	.1266	.1266
Hip breadth	.3569 a	.1806	-.2470	-.1600	.5863 ***	.5366 **	-.4417 *	-.4417 *
Upper limb length	.6026 ***	.2785	-.0217	.1842	.5169 **	.4288 *	-.0434	-.0721

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001



Postural angles and anthropometry

Arm flexion and elbow angle significantly positively correlated with taller subjects as defined by stature, sitting height, buttock knee length, knee height and upper limb length (Table 54). These correlations were not apparent when males and females were considered separately. A significant negative correlation between trunk-thigh angle and hip breadth indicates that subjects with a larger hip breadth tended to sit more upright. Further analysis showed that the top 31% largest hip breadths were female, implying that as mentioned previously it was females who sat more upright.

Table 54. Correlation coefficients (Pearson's r) for postural angles and anthropometric measurements (n=55).

	Ankle Angle	**Arm Flexion**	**Elbow Angle**	**Knee Angle**	**Neck Inclination**	**Trunk-thigh Angle**
Stature	.2508 a	.3573 **	.4333 ***	.1054	.0373	.0363
Weight	.1522	.0534	.2104	-.0069	.2355 a	-.3072 *
Sitting height	.2100	.3138 *	.4844 ***	.0695	-.0624	1.000
Buttock knee length	.3210 *	.2759 *	.3169 *	.0078	.0878	-.1487
Knee height	.2281 a	.3097 *	.3866 **	.0974	.1230	.0412
Hip breadth	.0046	-.1170	-.0298	-.0911	.0944	-.4322 ***
Upper limb length	.2500 a	.3338 *	.3958 **	.0872	.1603	-.0219

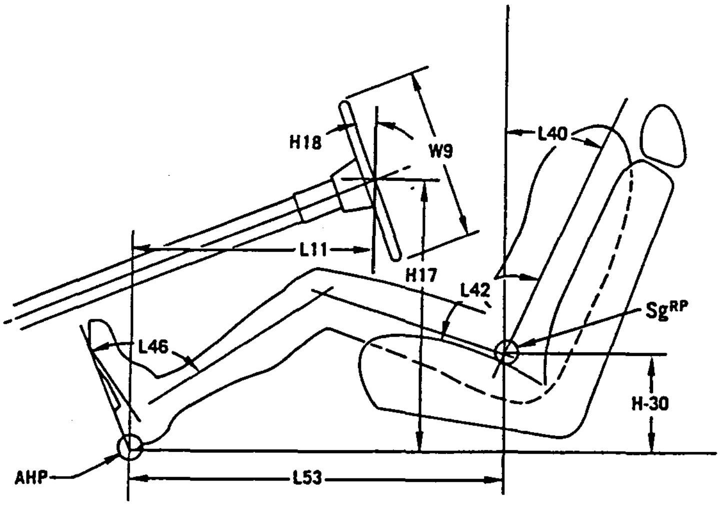
N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001

As expected both trunk-thigh angle, knee angle and neck inclination positively correlated with seat angle (L42) and seat back angle (L40), shown in Table 55. Arm flexion was also significantly positively correlated with the steering wheel distance from the body (L53-L11) and the height of the steering wheel in relation to the body (H17-H30). This implies that the preferred driving posture of taller subjects (mainly males) was with arms outstretched and the steering wheel position higher and further away in relation to their body. There was a negative correlation between trunk-thigh angle with the height of the steering wheel in relation to the body. In other words the larger the trunk-thigh angle the lower the steering wheel position in relation to their body. Once again these correlations were not significant when males and females were considered separately.

Table 55. Correlation coefficients (Pearson's r) for postural angles and H-point dimensions (n=55).

	L53-L11	H17-H30	L40	L42
Ankle Angle	.1416	.1717	.0984	.2063
Arm Flexion	.4873 ***	.3195 *	.1707	.1648
Elbow Angle	.6812 ***	.1175	.1212	.1179
Knee Angle	.0879	-.1685	.2687 *	.2783 *
Neck Inclination	.0605	.0461	.2829 *	.3239 *
Trunk-thigh Angle	-.0995	-.4182 ***	.5198 ***	.3729 **

N.B. NS = Not Significant, (a)=0.1>p>0.05, * $p<0.05$, ** $p<0.01$, *** $p<0.001$



Considering the interrelations between postural angles for the whole sample, there were only two significant (positive) correlations; they were between trunk-thigh angle and knee angle (correlation coefficient 0.3721, $p<0.01$) and between arm flexion and elbow angle (correlation coefficient 0.7698, $p<0.001$). The former was probably influenced by limitations in the flexibility of the hamstring muscles.

10.4 Discussion

Postural angles

Knee angle and foot-calf angle were very similar to the theoretical recommendations of Rebiffe (1969) and Grandjean (1980). However, generally subjects preferred to sit more upright (smaller trunk-thigh angle) than previously recommended. Neck inclination, arm flexion, and elbow angle were well outside i.e. greater than the range of any recommendations. Males generally preferred a more reclined posture and females a more flexed, upright posture with significant differences in arm flexion, elbow angle and trunk-thigh angle. This was found to be a body size difference rather than a sex difference and subjects perhaps adopting similar postures as in their own cars, tall males being unable to sit upright in their own car. Also, due to limitations in the flexibility of the hamstring muscles, the trunk-thigh angle was dependant on knee angle. It would therefore be impossible for a tall male to sit upright and stretch out his legs to operate the pedals; he would need to increase knee flexion in this instance. This would not be possible within the constraints of the design of the rig i.e. the rig was designed to simulate realistic postures for cars, not the upright postures possible in vans, buses and trucks.

Positions of the controls

The maximum values with reference to the H-point (SAE Handbook, 1985) calculated from the rig exceeded these measurements in a range of commercially available cars, implying that at present no car on that list will fit all users comfortably (Appendix 11). For example, for the measurement L53 (H-point to heel point), one subject required 889 mm, meaning that he would comfortably fit in only two out of thirty well known cars. Even more alarming, the mean H17 (floor to steering wheel centre) measurement on the rig was 628 mm but 26 out of 30 cars had an H17 measurement higher than this, implying that there is a need for a lower steering wheel position. It may be that the steering wheel is fixed high to ensure leg-room particularly in subjects who prefer a more upright posture. This will have a knock-on effect of making more leg-room available in the back seat. Larger subjects, both males and females also preferred the steering wheel further away from the body.

Unsurprisingly, when considering the anthropometric data, larger subjects required a larger driving space as defined by increased backrest angle, seat angle and rig measurements with reference to the H-point (SAE Handbook, 1985).

The validity of the data regarding posture and the positions of the controls from a static driving rig must be considered. It is likely that subjects do adopt different postures due to the constraints imposed by different vehicles in order to obtain optimum visibility of the road, ease of reach to the controls and driving comfort. Inevitably compromises will have to be made and these are all also affected by unique conditions such as a worn out foam in the car seat lowering the eye level and the clutch biting point affecting stretch to the clutch. This confounding is difficult to control for when measuring both static and dynamic postures in different vehicles. Rebiffe (1969) and Grandjean (1980) both based their analyses of a comfortable driving posture on the theoretical requirements of the driving task. In the light of this, the optimum postural angles for driving obtained by subjects using a standardised car seat on the driving rig must also be a good estimate. However, further work is needed to determine how much an individual's posture varies with different vehicles and in different driving situations. The fact that there was no restriction in headroom space on the rig however does mean that these optimum postures may not be achievable in many vehicles with taller subjects.

Seat Feature Checklist

Initial impressions of the seat design itself showed that 81% of males and 43% of females would have preferred the seat cushion to be longer and 43% of males and 24% of females would have preferred the seat cushion to be wider. The seat design itself could then have contributed to any discomfort with the seat and so had an effect on preferred posture. This was however likely to be minimal in this 'showroom style' analysis. Although this seat had the feature of in / out adjustment in the lumbar support, 38% adjusted it to its minimum setting and 61% adjusted it to considerably less than its maximum setting (one fifth of maximum). It could be that some of these subjects would have preferred less shaping in the lumbar area of the seat back or the feature of height adjustment in the lumbar support. Porter and Norris (1987) recommended a range of 195-260 mm of adjustment from the compressed seat cushion to the centre of the lumbar support, whereas this seat had a fixed lumbar support height of approximately 225 mm. Efforts to compare the in / out adjustment of the lumbar support with the literature were not possible due to potential for error in measurement.

10.5 Conclusions

1. Tall subjects (males) preferred a more reclined posture but this could be due to a constraint of the rig, which limited the maximum seat to floor height to a level which was realistic in cars thereby limiting hip and knee flexion. Shorter subjects (females) preferred a more flexed and upright posture, the rig being able to accommodate the increased flexion in the hip and consequently the knee.

2. At present it is highly likely that car drivers, especially those at the larger end of the extremes of anthropometric dimensions, have to compromise their preferred driving position in order to fit in the majority of cars. This could have serious implications for the future with evidence of an almost world-wide secular trend for an increase in body size (Pheasant, 1988 and NASA, 1978).

3. The Seat Feature Checklist revealed useful subjective information regarding an individuals' first impressions of a car seat as would be the case in a car showroom.

4. New guidelines for optimum postural comfort have been observed (Table 51). These ranges are:

    - Trunk-thigh angle 89-112 degrees.
    - Neck inclination 29-63 degrees.
    - Arm flexion 16-74 degrees.
    - Elbow angle 80-161 degrees.

    Subjects generally preferred to sit slightly more upright (smaller trunk-thigh angle) than recommended by Rebiffe (1969) and Grandjean (1980) with their arms more extended. The latter could be due to the effects of power steering or a smaller steering wheel diameter in newer cars.

The final discussion and conclusions regarding this work are presented in Chapter 13 together with those for Experiments 2 and 3.

Chapter 11 Experiment 2 - Fixed posture: Comparison of Preferred and Least Preferred Seats

11.1 Introduction

The main aim of this experiment was to begin to look at objective and subjective methods as predictors of car seat discomfort. In particular the method of collecting interface pressure data using the Talley Pressure Monitor (TPM) was explored as a predictive tool. In this study optimum postures were held constant within subjects but not between subjects, as drivers do not adopt identical postures. It could be expected that there would be higher correlations with interface pressure if subjects held identical postures but this was not a realistic situation. The definitive test would be to see if seat interface pressure data could be used to predict reported discomfort within the design arena by using identical seat design (profile, dimensions), and just changing foam density within a production range of foam hardnesses.

The experimental rationale is explained more fully in Chapter 8.5. Briefly each subjects preferred and least preferred seats (from seven experimental seats) were selected by the method of paired comparisons (Section 11.2.1). Subjects then sat in each of their preferred and least preferred seats for the driving trials using the rig (11.2.2) whilst the data were collected. The results, discussion and conclusions are also presented in this chapter.

11.2 Experimental Procedure

Sessions involving the method of paired comparisons and two medium term static driving trials were completed by 14 carefully selected subjects using a repeated measures design. The selection criteria are described in Chapter 10.2. In addition, subjects were asked to wear clothing without heavy seams, buttons or pockets in order that there was a minimal effect on the interface pressure readings. The results of their optimum driving postures and the positions of the controls are reported and discussed in Chapter 10. Environmental and procedural conditions were once again held constant.

11.2.1 The Method of Paired Comparisons

The method of paired comparisons is described in Chapter 8.2.3. The seven experimental car seats (see 9.3.2 for detail) were numbered and each fitted to a stand, so that the height and seat angle mimicked the production Fiat Tipo C. Each subject was instructed to work down a list of the 21 pairings commencing at a different starting position (Appendix 13). For each seat they adjusted the backrest angle for comfort, mimicked driving and then made a choice between the two seats in the pairing as to their preferred backrest, seat cushion and overall seat. Subjects could test each seat as many times as they wished for each comparative judgement, but were advised not to deliberate for too long with their decision. The analysis identified each subjects preferred and least preferred seat, the difference being foam hardness only.

11.2.2 The Static Driving Trials

Each subjects optimum posture and position of the controls was obtained by the method of fitting trials (as explained in Chapter 8.2.4) and confirmed by a 10-15 minute driving simulation. The presentation of the preferred and least preferred seats to the subjects for the fitting trials was balanced. In the next two sessions subjects sat in each of their preferred and least preferred seats for 2.5 hour static driving trials. Subjects mimicked the driving task following the audio instructions of the driving video and using the controls as appropriate without further adjustment of the seat / steering wheel / pedals. The position of the controls, and consequently the driving posture was held constant.

Prior to the commencement of each driving trial, subjects completed a Seat Feature Checklist, a predictive Seat Detail Questionnaire and body part comfort / discomfort charts (Appendices 10 and 14). Every 30 minutes subjects completed a further comfort chart and postural angles were measured half way through each trial. At the end of each trial the final comfort chart and Seat Detail Questionnaire were completed. Finally the cell matrix was positioned on the seat and interface pressure readings using the Talley Pressure Monitor (TPM) were taken whilst they assumed their driving posture.

11.3 Data Analysis

Once again all the data exploration and analyses were performed using SPSS for Mackintosh Computers (Norusis, 1990) and the following were computed in addition to the basic descriptive statistics.

Wilcoxon's Matched-Pairs Signed Ranks Test

This non-parametric test was used for comparisons between two related samples. For example, is the discomfort experienced in each body area over each time period significantly different between the preferred and least preferred seat conditions?

Mann-Whitney U test

This was used as an alternative to the students t-test when assumptions were not met or the data was not on an interval scale. For example, when using the Seat Detail questionnaire to obtain subjects who reported the seat was 'too hard' or 'just right' in the IT, thigh or low back areas, it was used to compare the discomfort variables between the two groups.

Spearman's Rank Correlation Coefficient

This gives a measure of association between two variables which are at least on an ordinal scale. It was used for correlations with the discomfort data.

Students t-test

This statistic was used on the interval data, for example the pressure data (mmHg), to determine whether the means of two independent samples, for example males and females or the preferred and least preferred seat differ. It compares the differences between the means of the two samples with the probability of those two means differing by chance.

Pearson's r Correlation

This statistic gives a measure of linear association, assessing the extent to which high scores on one variable were related to high scores on another variable. It also assesses the strength, direction and probability of the association. The data must be interval or ratio level, for example weight, pressure data and posture data.

Multiple Regression Analysis

Multiple regression analysis was used to explore the variables important in contributing to the interface pressure values. Readers should once again refer to Glantz and Slinker (1990) for further detail regarding the technique and the terminology used in the text.

A description of the initial interface pressure variables calculated is given in Appendix 8, the quantification of which is described in Chapter 9.2.5. Not all of these variables provided useful information concerning interface pressure. For example, the maximum reading for the 'whole seat' was always identical to that for the IT area; statistical analyses using the variables of the 'whole seat' tended to reflect those for the IT area; statistical analyses of the 'cell total' variables for the IT, thigh and low back areas were same as those for the 'mean'; and the IT, thigh and low back 'ratio' pressure variables were generally unreliable. Overall the 'mean' pressure values were felt to be the most consistent and least prone to error. Consequently, to avoid the lengthy (and confusing) presentation of the data for all 25 variables, only the analyses of selective pressure values are reported in this thesis. These variables were selected for their suitability for comparison with other studies and were judged for their stability in reflecting (or describing) the individual interface pressure maps.

11.4 Results

11.4.1 Summary Statistics for Experiment 2

Subjects

The sample consisted of seven males with a mean age of 40.7 years (SD 17.9) and seven females with a mean age of 42.86 years (SD 11.9). The range of anthropometric measurements in the sample is shown in Appendix 15.

Seat Feature Checklist

Once again most subjects were able to obtain a good position with regard to seat height adjustment, however 43% of subjects would have preferred the seats to be longer and 21% would have preferred the seat to be wider. This implies that some subjects may not have been completely comfortable with the driving package.

Subjects were generally happy with the dimensions of the seat back, although half of the subjects would have preferred the lumbar support to be higher (21%) or lower (29%) than its existing position.

11.4.2 Results of the Method of Paired Comparisons

The results of the static comfort assessment using the method of paired comparisons are shown in Figure 35. The reader should refer to Table 49, Section 9.3.2 for a description of the seats. The three worst ranked seats had the hardest seat cushion (seats 1, 2 and 6) and the two worst ranked seats also had the hardest backrests (seats 1 and 6). The combination seat cushion was preferred; seat 3 with its soft seat cushion front edge of 20 daN and its 'reference' seat cushion back of 37 daN. The 'reference' backrest of 18 daN was preferred. Seat 4 slightly softer all over, was the preferred seat overall. The reference seat (seat 7 - Tipo C) was also ranked highly. In this static 'showroom style' analysis it appears that views on the seat cushion overrode views on the backrest. For example, seat 2 (3rd worst seat) had the preferred 'reference' backrest but the seat cushion had a hard front edge. It must be remembered that the ranked order of the seats obtained by this technique is not on a proportional scale with a true zero and therefore the actual scale values are not absolute.

The results also agree with a pilot study which was conducted using the method of paired comparisons to aid evaluation of the seven experimental seats. In this case ten different subjects to those in the main experiment were used and the results were identical with regard to the best seat cushion, best backrest, best overall seat and the two worst seats (Figure 36).

Figure 35 . Static comfort assessment using the method of paired comparisons (n=14).

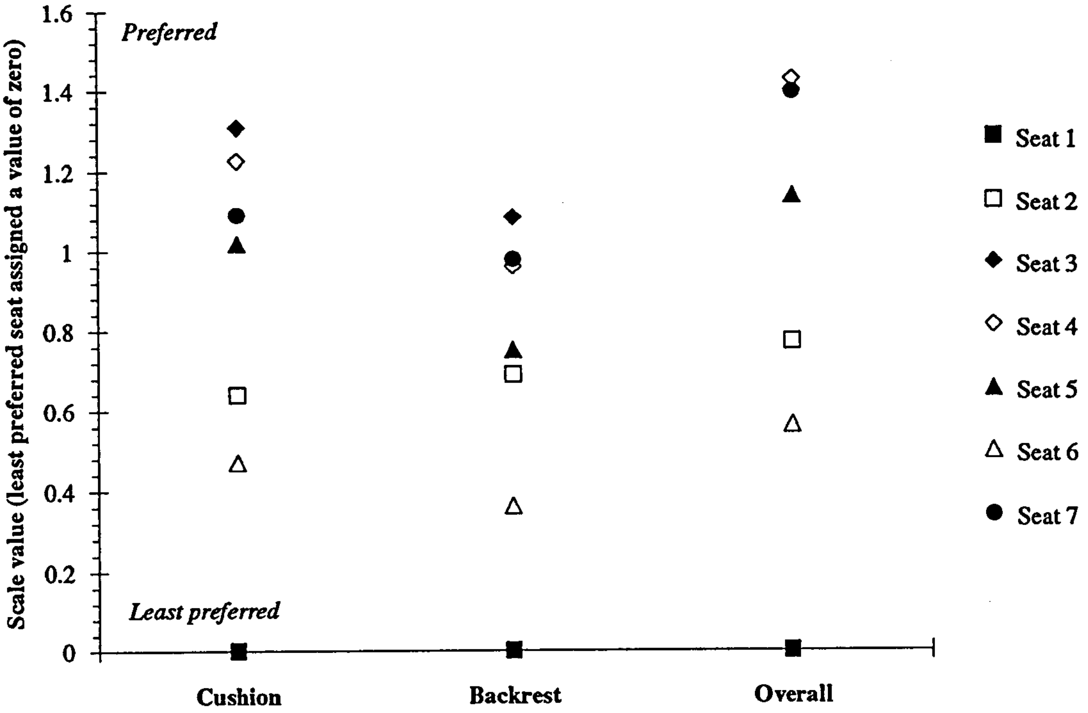
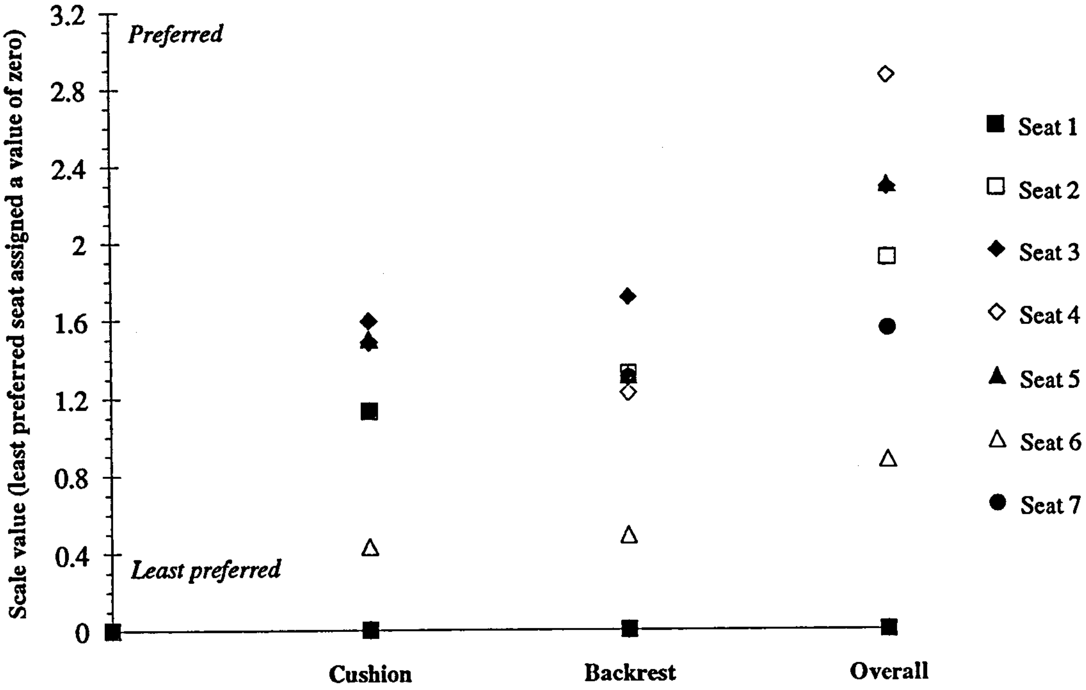


Figure 36. Pilot trial for static comfort assessment using the method of paired comparisons (n=10).



The seats listed below in Table 56 were identified from the method of paired comparisons session for use in Experiment 2 and their presentation was balanced. It can be seen that for most subjects (in daN) the least preferred seat was harder in the lumbar area, IT and thigh areas.

Table 56. Car seats selected by subjects as preferred and least preferred.

Subject	**Seat No. Preferred**	**Seat No. Least Preferred**	**The difference in foam hardness between the two seats, with the preferred seat as a reference (daN) for different body areas.** Data supplied by Sepi, SPA, Turin.		
			Lumbar	**Buttocks (IT's)**	**Thighs**
1	3	1	+18.6	+11.4	+28.4
2	7	1	+18.6	+9.8	+9.8
3	5	1	+19.4	+21.2	+21.2
4	3	1	+18.6	+11.4	+28.4
5 **	7	4	-1	-6.6	-6.6
6	3	1	+18.6	+11.4	+28.4
7	4	1	+18.6	+16.4	+16.4
8	4	1	+18.6	+16.4	+16.4
9	3	1	+18.6	+11.4	+28.4
10	3	1	+18.6	+11.4	+28.4
11 *	3	2	0	+1	+30
12 **	1	5	-19.4	-21.2	-21.4
13	7	1	+18.6	+9.8	+9.8
14	5	1	+19.4	+21.2	+21.2

** Subjects whose least preferred seat was softer than the preferred in the lumbar, IT and thigh areas.
* Subjects whose least preferred seat was softer than the preferred in the lumbar and IT areas.
daN = deka Newtons

11.4.3 Body Part Comfort / Discomfort Charts

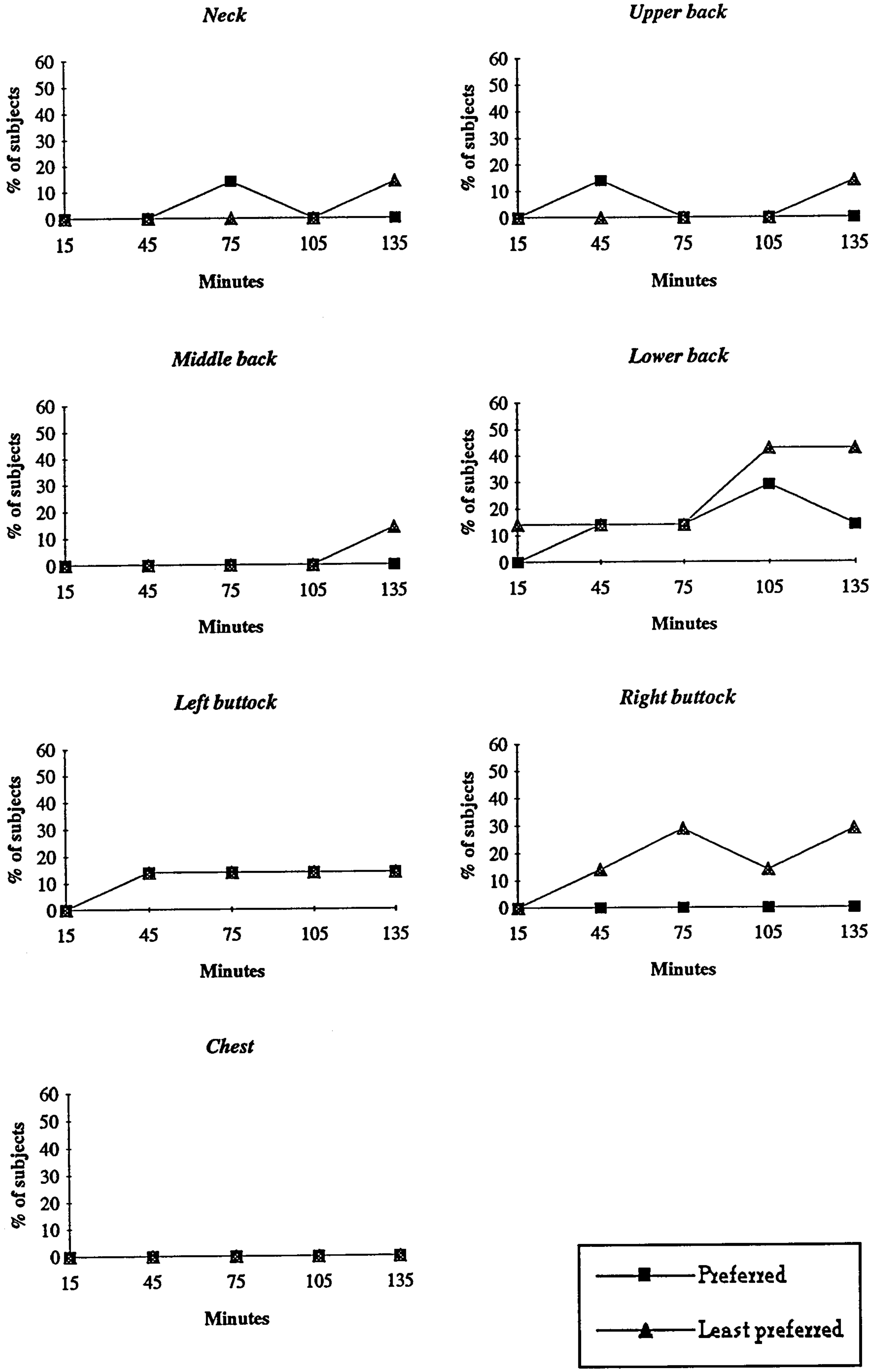
Figures 37 and 38 show the percentage of subjects reporting discomfort in each body area at each of the five time periods during the static trial for males and females separately. The graphs can be used to assess initial 'showroom style' comfort analysis (the first 15 minutes) and how discomfort develops over time (45, 75, 105 and 135 minutes). For example, no males reported discomfort in the right buttock after 15 minutes with the least preferred seat whereas after 135 minutes, 29% of males reported discomfort. There was a trend for slightly more discomfort in males with the least preferred seat in the low back, right buttock, right and left thigh and right foot and ankle, although Wilcoxon's and McNemar's tests for the significance of the differences between the two related samples showed that these differences were not significant. Considering females there were no significant differences or obvious trends in discomfort between the two conditions. Differences regarding discomfort between gender for each time period were insignificant apart from neck discomfort which was reported by more females. The fact that the differences in discomfort between the two seats were not significant, was likely to be due to the fact that in both conditions subjects were sat in their optimum posture and shows the importance of posture in the avoidance of discomfort.

A complimentary way of presenting the data (Figure 39) shows the mean number of minutes of reported discomfort during the 2.5 hour trial for each body area and for males and females separately. An overall picture of reported discomfort for each body area is presented by giving each of the five comfort evaluations a weighting of 30 minutes. The means can be seen to range from 0 to 60 minutes of reported discomfort, indicating which areas of the body experienced discomfort for the longest period of time. Using Wilcoxon's test, males reported significantly more discomfort in the right buttock ($p<0.05$), left and right thighs ($p<0.05$) and left foot and ankle ($p<0.05$) with their least preferred seat. For example there was a mean of 39 minutes of reported discomfort in the right thigh with the least preferred seat but no discomfort with the preferred seat. There were no significant differences in minutes of reported discomfort for females between the two conditions. Although in Figure 39 there does appear to be a slight trend for slightly more discomfort for females with their preferred seat, in the neck, mid and low back, left and right buttock and right thigh areas. This was thought likely to be due the small subject numbers making the impact of one person on the results more dramatic. It was judged that generally discomfort between the two seats were similar for females.

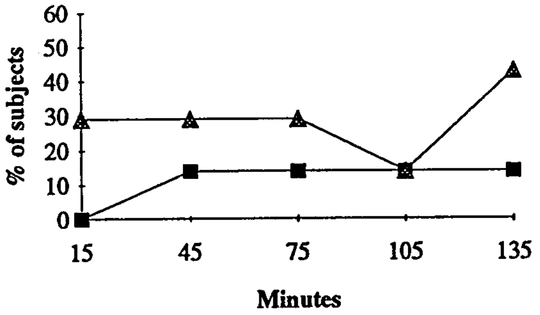
11.4.4 Interface Pressure Descriptive Data

Some of the descriptive data for the IT area, thigh area and low back are shown in Table 57. Refer also to Appendix 8. A trend for higher pressure values with the least preferred seat (with the exception of 'sum of cells' in the IT area for females) can be seen.

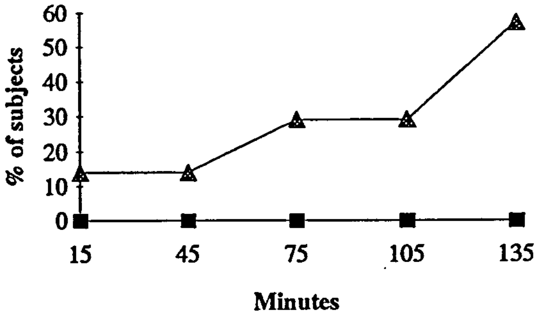
Figure 37. Percentage of males reporting discomfort in different body areas (n=7).



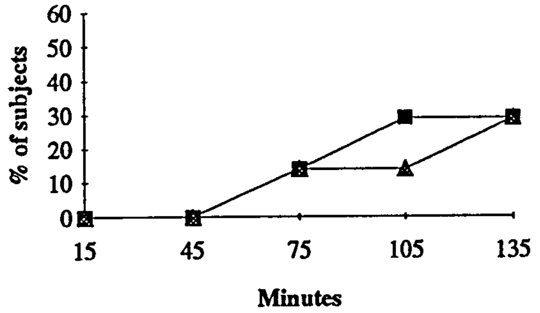
Left thigh



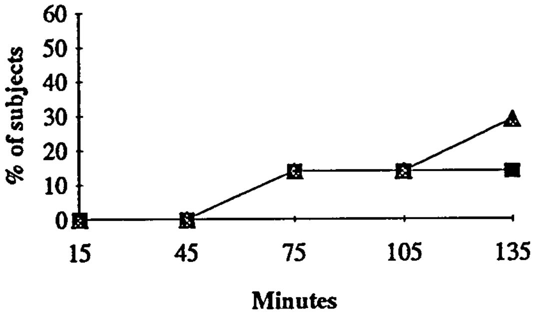
Right thigh



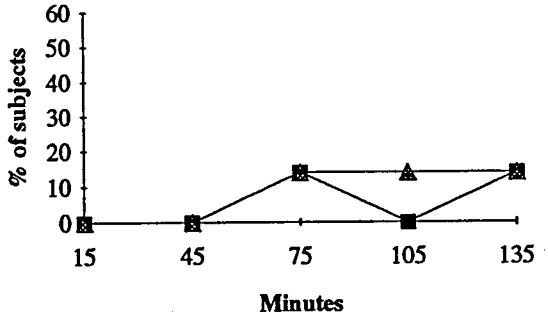
Left knee



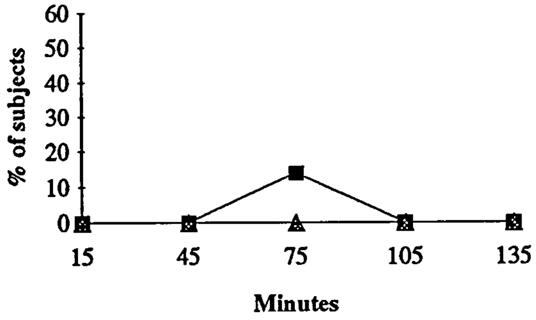
Right knee



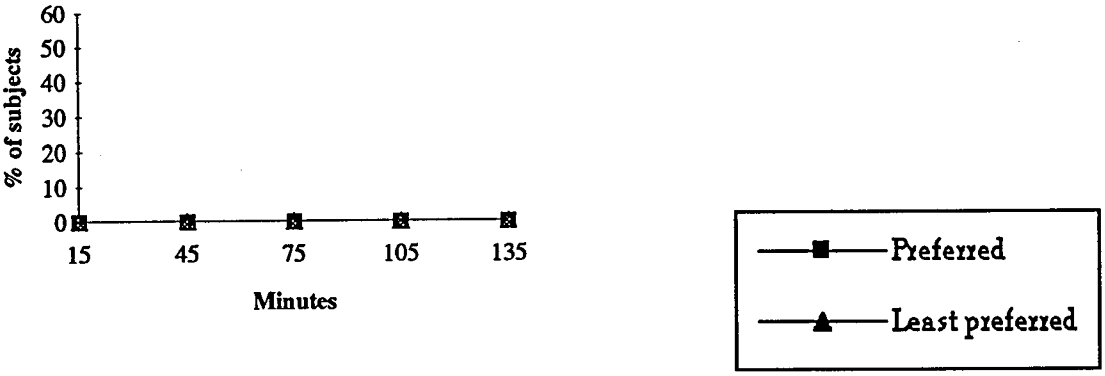
Left shoulder



Right shoulder



Stomach



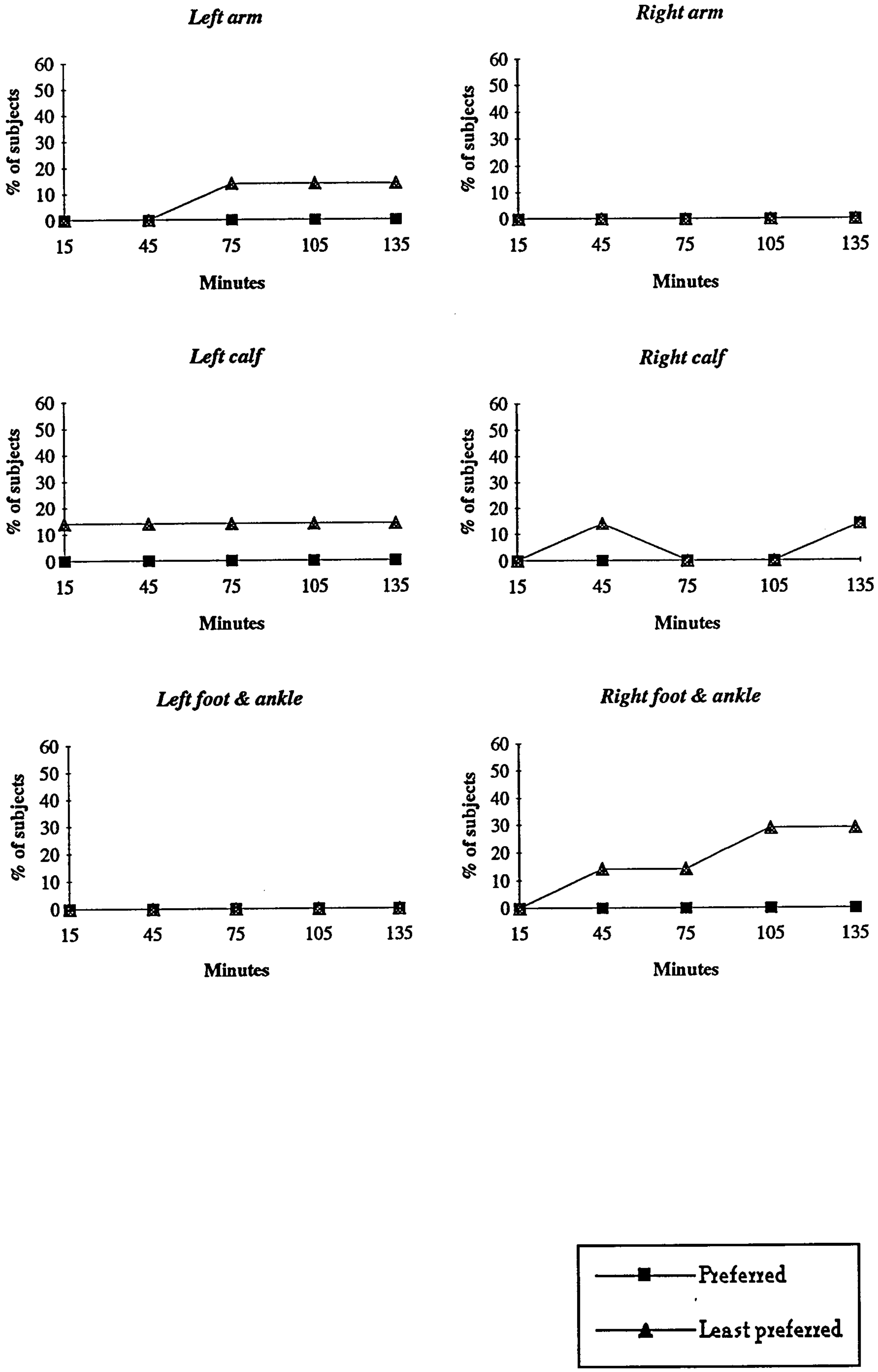
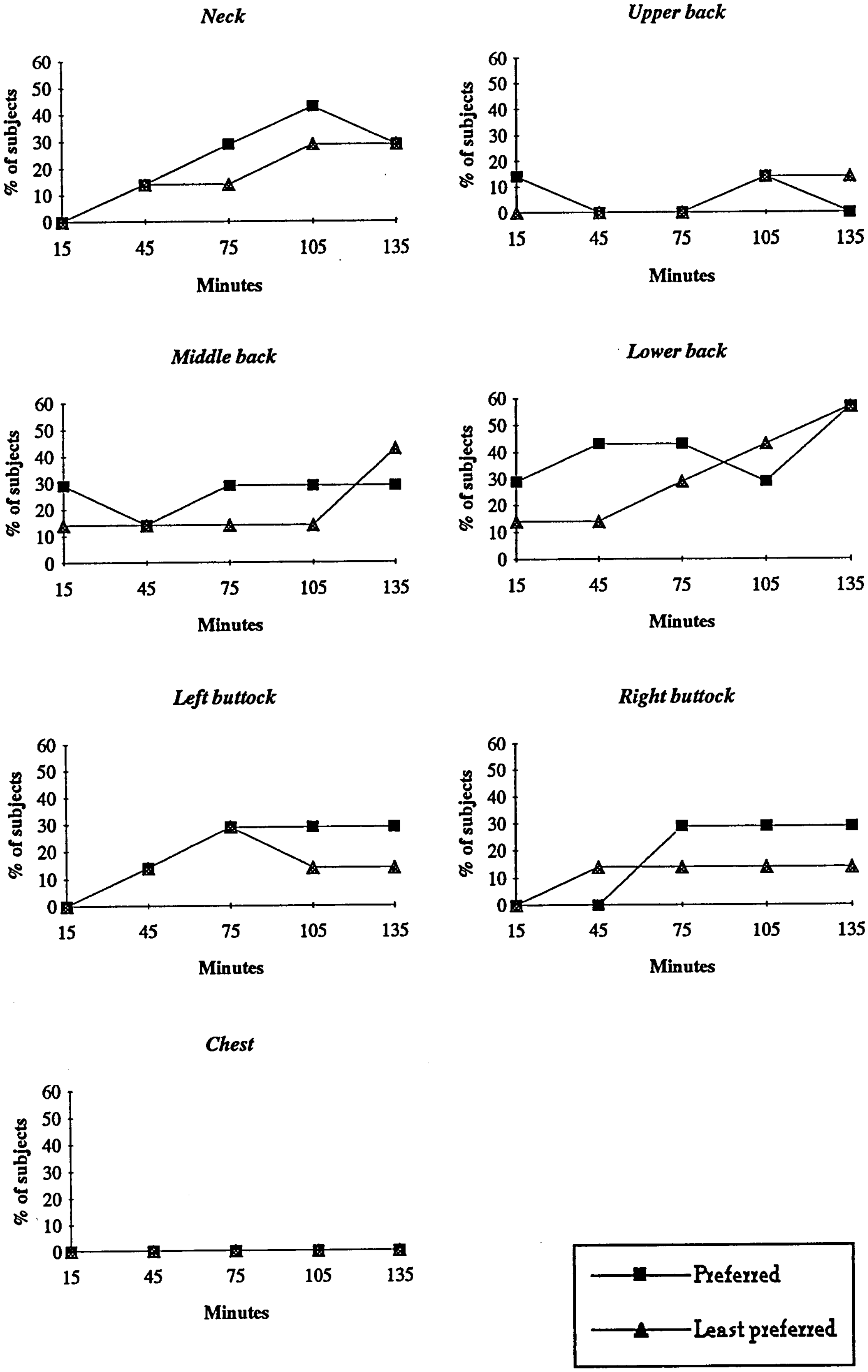

Left arm
Right arm
Left calf
Right calf
Left foot & ankle
Right foot & ankle
% of subjects
0
10
20
30
40
50
60
15
45
75
105
135
Minutes
Preferred
Least preferred

Figure 38. Percentage of females reporting discomfort in different body areas (n=7).



Neck

Upper back

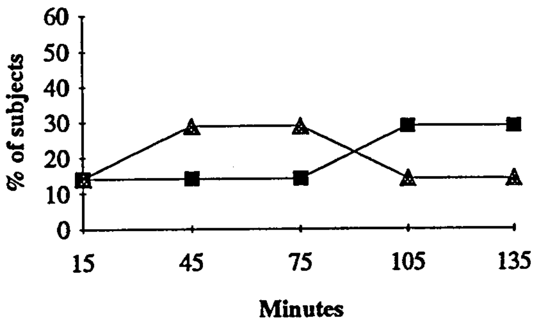
Middle back

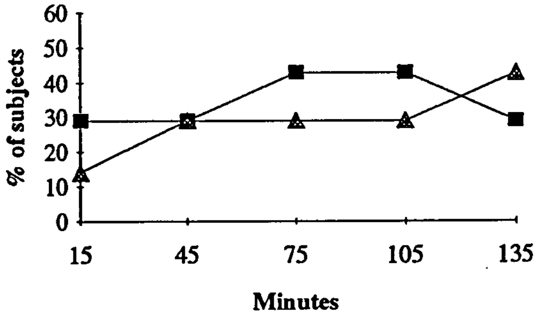
Lower back

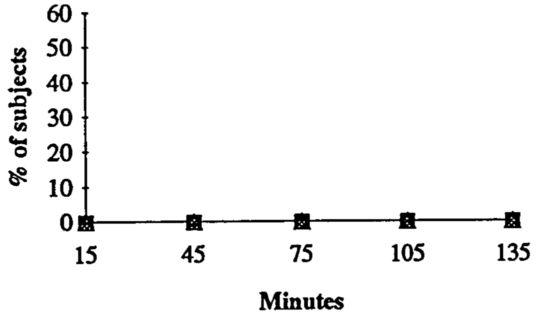
Left buttock

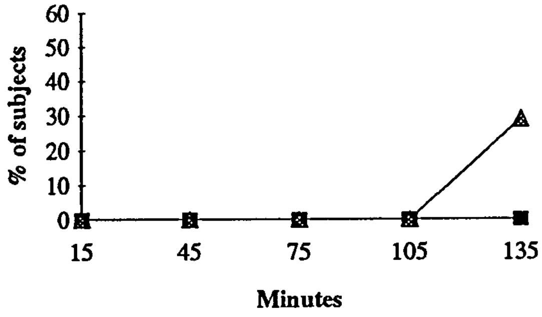
Right buttock

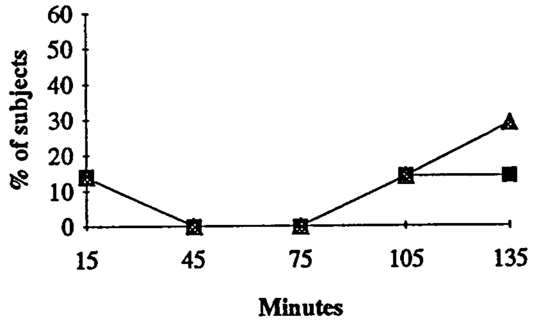
Chest

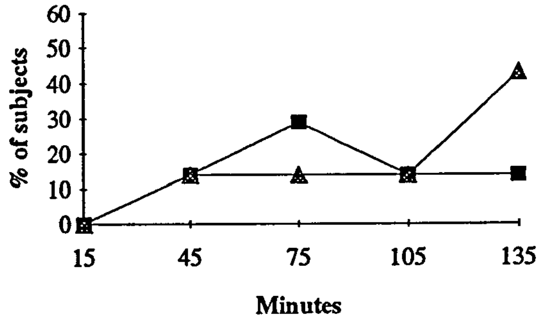

Left thigh

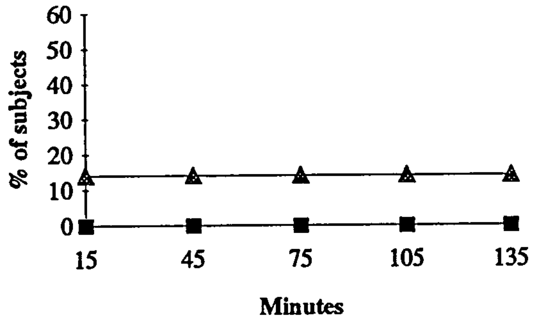

Right thigh


Left knee


Right knee


Left shoulder


Right shoulder


Stomach

■ Preferred

▲ Least preferred

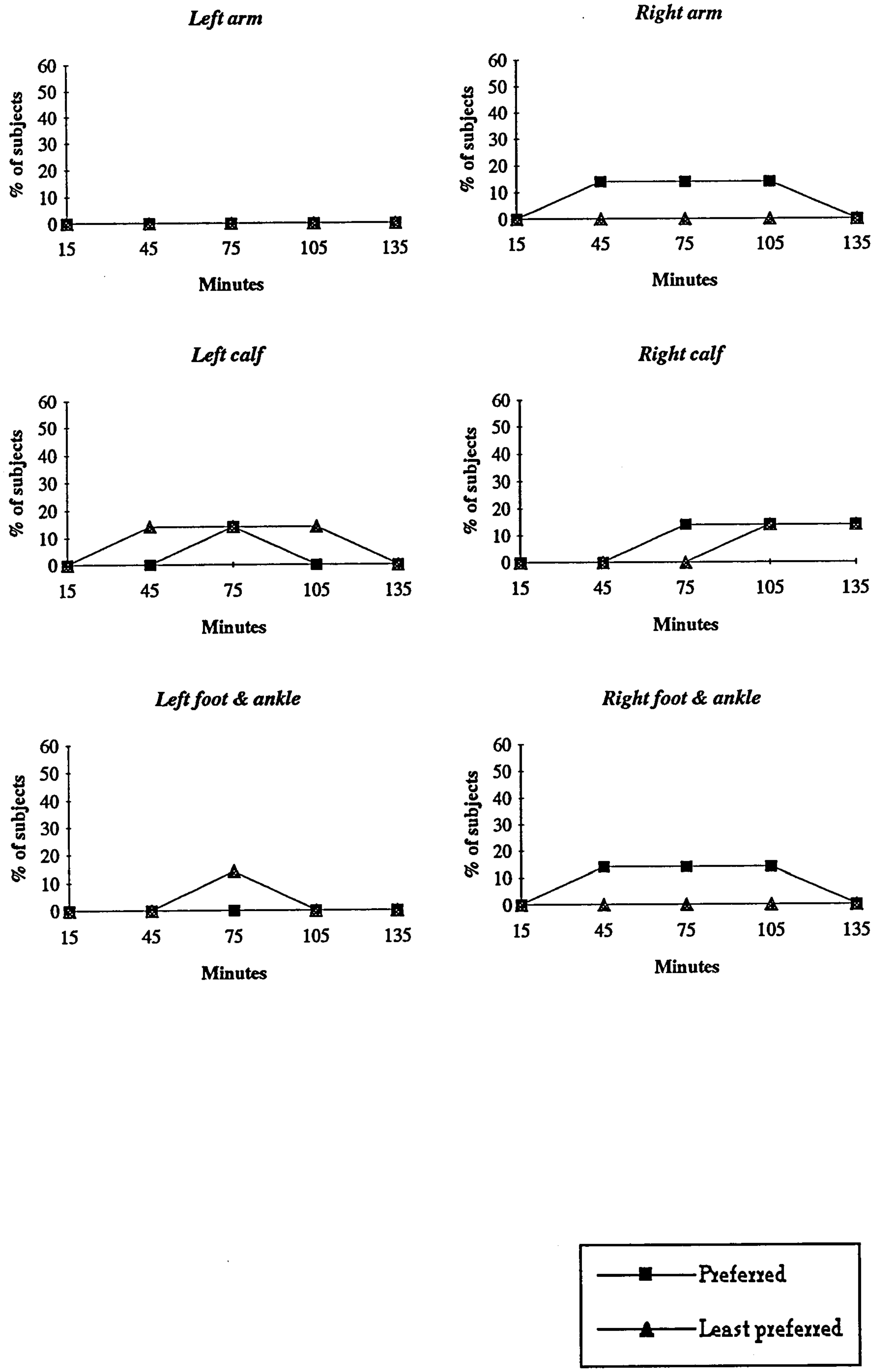
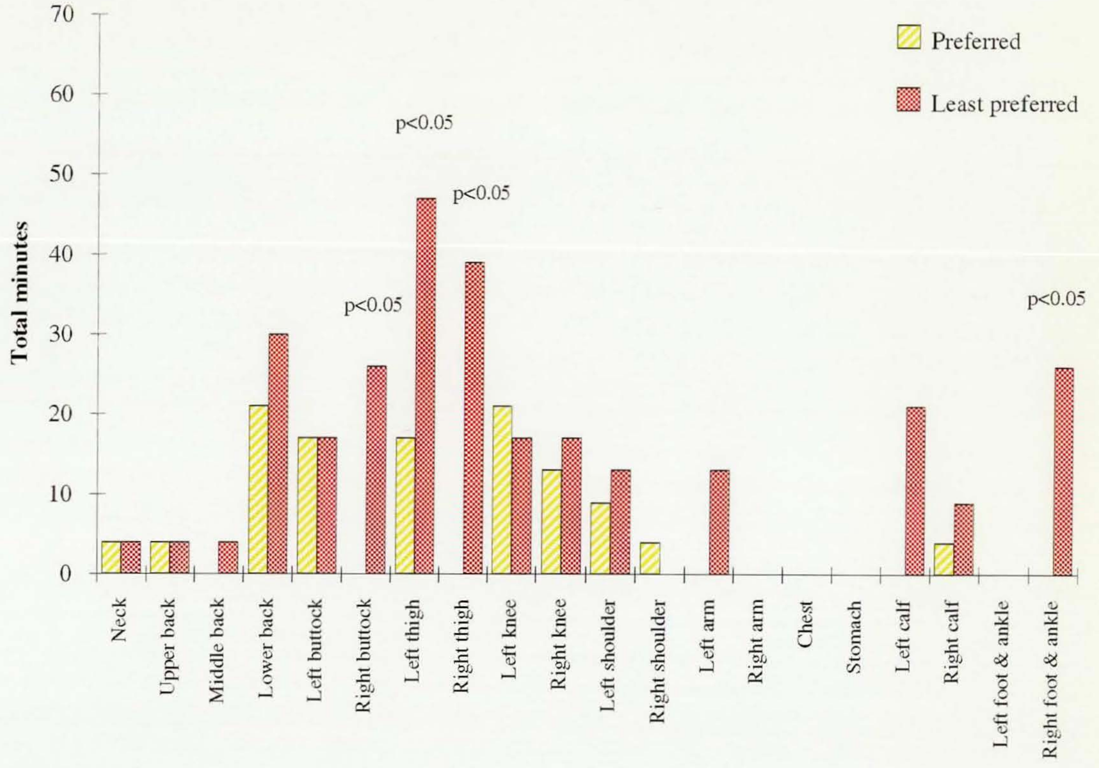

Left arm
Right arm
Left calf
Right calf
Left foot & ankle
Right foot & ankle
% of subjects
0
10
20
30
40
50
60
Minutes
15
45
75
105
135
Preferred
Least preferred

Figure 39. Total minutes of reported discomfort (n=14).

Males (n=7)



Females (n=7)

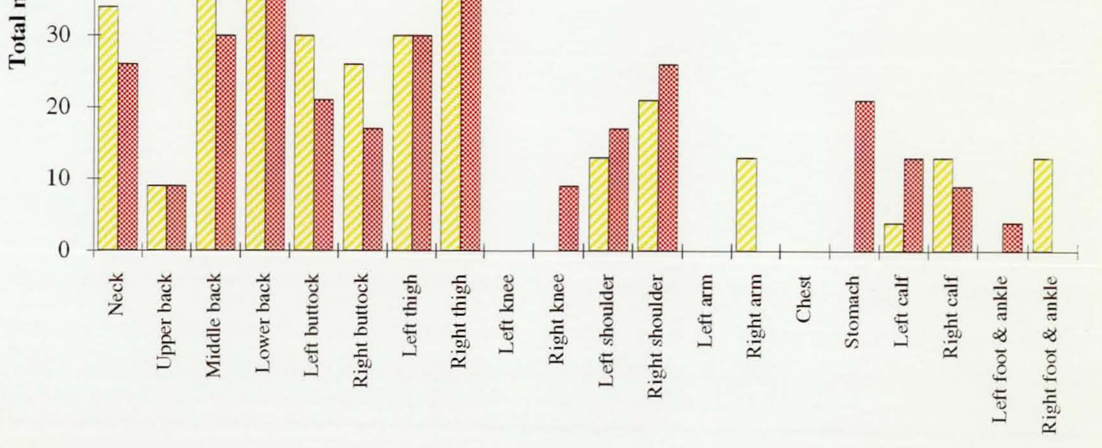


Table 57. Pressure values and significant differences between preferred and least preferred seats (n=14).

	Males (n=7)			Females (n=7)		
Pressure value	**Preferred Seat**	**Least Preferred Seat**	**Sig.**	**Preferred Seat**	**Least Preferred Seat**	**Sig.**
Low back						
Mean	29.3 (4.8) 22-34	34.8 (12.7) 19-58	NS	23.3 (3.7) 19-29	26.8 (8.1) 16-35	NS
Maximum	61.7 (30.5) 33-111	66 (40.4) 28-125	NS	38 (8.2) 25-48	47.9 (18.2) 27-68	NS
Sum of cells	653 (168.3) 439-866	823 (333.9) 338-1279	(a)	587 (190.1) 377-848	694 (389.9) 260-1200	NS
Right IT						
Mean	57.3 (6.4) 52-69	63.7 (11.5) 49-79	NS	45.4 (5.3) 39-53	48.9 (6.3) 41-56	NS
Maximum	82.3 (20.7) 56-109	93.4 (24.3) 66-130	NS	62 (14.6) 47-90	75.7 (20.7) 53-106	(a)
Sum of cells	516 (57.8) 469-622	573 (103.1) 437-709	NS	408 (47.5) 349-474	340 (56.9) 367-504	NS
Proportion of seat area	0.25 (0.05) 0.19-0.33	0.28 (0.05) 0.18-0.34	*	0.22 (0.04) 0.15-0.26	0.26 (0.06) 0.14-0.33	*
Right Thigh						
Mean	37.4 (7.2) 27-48	39.8 (6.5) 31-48	NS	32.9 (9) 26-52	34.2 (12.7) 25-60	NS
Maximum	47.7 (10.9) 30-65	53 (8.8) 38-64	(a)	41.6 (7.2) 35-56	47.6 (23.4) 30-98	NS
Sum of cells	516 (57.8) 469-622	573 (103.1) 437-709	NS	264 (72.4) 208-415	274 (101.5) 196-483	NS
Proportion of seat area	0.15 (0.02) 0.11-0.17	0.16 (0.03) 0.13-0.19	NS	0.14 (0.03) 0.11-0.18	0.15 (0.02) 0.12-0.18	NS

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

11.4.5 Interrelations Between Gender, Body Build and Interface Pressure

Gender differences

Under both conditions there was a trend for males to have higher pressure values than females, significantly so under the IT area for the mean ($p<0.01$). There was a significant gender difference, but for the preferred seat only, for back mean ($p<0.05$), and back maximum and IT maximum were approaching significance, all showing higher pressures for the males (Table 58).

Body build and weight

The correlation coefficients for body build and weight with pressure are shown in Table 59 for males and females combined. The Reciprocal Ponder Index or RPI (Yang et al 1984) was used as a measurement of a persons body build relative to others. It is calculated by dividing body length in centimetres by the cubed root of body weight in kilograms. The values for this sample are shown in Appendix 15. A high value indicates a narrow, thin body and a low value indicates a wide body build. As this index had been used in the above pressure measurement study it was thought suitable for this study. The IT pressure values of 'mean' and in particular 'proportion' were the best correlates with body build. Analysis of the data for males and females separately also revealed the same significant trend. This implies that thinner (higher RPI) individuals have higher pressures under the IT's.

Weight, on the other hand, was a more consistent correlate with thigh pressure values, with heavier individuals having the higher pressures.

Table 58. Pressure values and significant differences between males and females (n=14).

	Preferred Seat (n=14) Mean (SD)			Least Preferred Seat (n=14) Mean (SD)		
Pressure value	**Males**	**Females**	**Sig.**	**Males**	**Females**	**Sig.**
Low back						
Mean	29.35 (4.77)	23.32 (3.73)	*	34.81 (12.69)	26.76 (8.1)	NS
Maximum	61.72 (30.5)	38 (8.25)	(a)	66 (40.37)	47.86 (18.16)	NS
Sum of cells	653 (168.3)	587 (190.1)	NS	823 (333.9)	694 (389.9)	NS
Right IT						
Mean	57.32 (6.4)	45.37 (5.28)	**	63.66 (11.45)	48.85 (6.33)	*
Maximum	82.29 (20.7)	62 (14.59)	(a)	93.43 (24.28)	75.71 (20.68)	NS
Sum of cells	516 (57.8)	408 (47.5)	**	408 (47.5)	340 (56.9)	*
Proportion of seat area	0.25 (.05)	0.22 (.04)	NS	0.28 (.05)	0.26 (.06)	NS
Right Thigh						
Mean	37.43 (7.1)	32.95 (9)	NS	39.82 (6.48)	34.19 (12.68)	NS
Maximum	47.71 (10.8)	41.57 (7.2)	NS	53 (8.81)	47.57 (23.39)	NS
Sum of cells	516 (57.8)	264 (72.4)	NS	573 (103.1)	274 (101.5)	NS
Proportion of seat area	0.15 (.02)	0.15 (.02)	NS	0.16 (.02)	0.15 (.02)	NS

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 59. Correlation coefficients (Pearson's r) and significance for body build, weight and interface pressure for their preferred and least preferred seats (n=14).

Pressure Variable	**Correlation Coefficients**			
	Body Build (RPI)		**Weight**	
	Preferred Seat	**Least Preferred Seat**	**Preferred Seat**	**Least Preferred Seat**
Right Ischial Tuberosities (IT)				
IT Maximum	.5964 *	.4427	-.2711	-.2698
IT Mean	.7960 ***	.4954 (a)	-.0140	-.2213
IT Standard Deviation	.5040 (a)	.3122	-.3566	-.3762
IT Ratio Maximum	-.4671 (a)	.0118	.4140	.1749
IT Ratio Minimum	-.0856	-.4671 (a)	.2826	.4140
IT Proportion	.9042 ****	.8204 ****	-.5097 (a)	-.6503 *
Right Thigh				
Thigh Maximum	-.4947 (a)	-.4966 (a)	.4259	.6892 **
Thigh Mean	-.5723 *	-.3854	.6886 **	.5973 *
Thigh Standard Deviation	.1819	-.2865	-.3169	.4722 (a)
Thigh Ratio Maximum	-.3251	-.0439	.6261 *	-.1446
Thigh Ratio Minimum	.1091	.4201	.3641	-.3139
Thigh Proportion	-.4421	-.1311	.2699	.1615
Low Back				
Back Maximum	.1871	.4262	.1101	.0211
Back Mean	.4812 (a)	.2616	-.0013	.1987
Back Standard Deviation	.1422	.5106 (a)	.0889	-.0839
Back Ratio Maximum	-.1055	-.5228 (a)	.1948	.5314 *
Back Ratio Minimum	.1998	-.4037	-.4783	.2138

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001

11.4.6 Interrelations Between Posture and Interface Pressure

The relationship between posture and pressure was not clear (Appendix 16 for correlations). It was expected that any significant correlations would be repeated under both conditions (preferred and least preferred seats), due to the fact that posture was held constant. However this was not the case in most instances with more significant correlations for the preferred seat condition. A significant negative correlation existed between IT pressure variables (maximum, mean and standard deviation) and ankle angle with the preferred seat. Significant negative correlations were also found between IT pressure variables (maximum, mean and proportion) and neck inclination with the preferred seat. Neck inclination also negatively correlated with back pressure variables (maximum, standard deviation and minimum back ratio) but this time with the least preferred seat only.

11.4.7 Interrelations Between Discomfort and Interface Pressure

In order to collapse the data, discomfort values for the five time periods were combined for left and right IT and thigh by taking the highest value for each. For example, if reported discomfort was 5 for the left buttock but 7 for the right buttock, the value 7 would be used for general buttock discomfort. The same procedure was carried out with the data for the total minutes of reported discomfort. The trends and significant trends for discomfort were similar to those presented in Section 11.4.3. Nine discomfort variables were then available for the correlations with the pressure variables. These were the following for each of the IT, thigh and low back areas:

- Total number of minutes of reported discomfort during the trial.
- Mean rank of discomfort for the trial.
- Discomfort rating after 135 minutes.

The correlation coefficients between the discomfort and pressure variables are shown in Tables 60 and 61 for males and females separately. It can be seen that there was no clear relationship with the discomfort variables in the buttock and thigh areas with both sexes. However, under the preferred seat condition in females only, there were significant negative correlations between low back pressure variables (maximum, mean and standard deviation) and discomfort variables i.e. the discomfort ratings were lower as pressure increased.

Table 60. Correlation coefficients (Spearman's rank) and their significance for discomfort and pressure variables with their preferred and least preferred seats - males (n=7).

Pressure Variable	Correlation Coefficients - Males					
	Mean Minutes		Mean Rank		135 Minutes	
	Pref. Seat	Least Pref. Seat	Pref. Seat	Least Pref. Seat	Pref. Seat	Least Pref. Seat
Right IT						
IT Maximum	-.2041	-.4009	-.0371	.3273	.0936	-.3181
IT Mean	-.2041	-.2673	-.3336	.3819	-.0936	-.2433
IT Standard Deviation	-.2041	-.7572 *	-.0371	-.0727	.0936	-.5426
IT Ratio Maximum	-.4082	.7572 *	-.3336	.5092	-.5052	.6362 (a)
IT Ratio Minimum	.4237	.0462	.0385	-.1698	-.0583	-.4466
IT Proportion	-.2041	-.4045	-.3336	-.3762	-.0936	-.3682
Right Thigh						
Thigh Maximum	-.4082	-.1652	.1123	.1071	-.2245	-.2245
Thigh Mean	-.4082	.0918	.0374	-.1429	-.2245	-.0748
Thigh Standard Deviation	-.4082	.0000	-.2245	.4286	-.5052	.1123
Thigh Ratio Maximum	.2060	.1101	.3682	-.3214	.5004	-.0374
Thigh Ratio Minimum	.0000	-.3488	-.2433	-.7143 *	-.0187	-.4304
Thigh Proportion	-.4157	-.3679	.1048	-.8994 **	-.1810	-.3270
Low Back						
Back Maximum	.7641 *	.1576	.3784	.1482	.4248	-.3930
Back Mean	.5791 (a)	.4729	.1429	.5559 (a)	.2245	-.0561
Back Standard Deviation	.7572 *	.1182	.4643	.2224	.5052	-.3181
Back Ratio Maximum	-.5791 (a)	.1576	-.4286	.0371	-.3368	.5801 (a)
Back Ratio Minimum	.7641 *	-.0099	-.3964	.2992	-.4437	.2738

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 61. Correlation coefficients (Spearman's rank) and their significance for discomfort and pressure variables with their preferred and least preferred seats - females (n=7).

Pressure Variable	**Correlation Coefficients - Females**					
	Mean Minutes		**Mean Rank**		**135 Minutes**	
	Pref. Seat	**Least Pref. Seat**	**Pref. Seat**	**Least Pref. Seat**	**Pref. Seat**	**Least Pref. Seat**
Right IT						
IT Maximum	.1348	.2227	-.1182	.4865	-.0550	.5092
IT Mean	-.5791 (a)	.2227	-.6487 (a)	.5586 (a)	-.6001 (a)	.5819 (a)
IT Standard Deviation	.2673	.2227	.2342	.4865	.3091	.5092
IT Ratio Maximum	-.2697	-.2227	-.2182	-.2342	-.2844	-.2182
IT Ratio Minimum	-.5345	.5345	-.1261	.2703	-.2182	.2364
IT Proportion	-.6804 *	.4270	-.3303	.6182 (a)	-.3333	.6239 (a)
Right Thigh						
Thigh Maximum	.7769 *	-.0371	.5189	-.2364	.6001 (a)	-.4546
Thigh Mean	.5427	.0000	.0935	-.2910	.2385	-.4546
Thigh Standard Deviation	-.1394	.1853	.0741	.0546	.0000	-.1091
Thigh Ratio Maximum	.6175 (a)	.2224	.3336	.1273	.4364	.1818
Thigh Ratio Minimum	.1709	.3366	-.2618	.3395	-.1101	.4496
Thigh Proportion	.5427	-.3553	.3740	-.5138	.4587	-.7615 *
Low Back						
Back Maximum	-.8524 **	-.1853	-.8929 **	-.2883	-.8365 **	-.3368
Back Mean	-.7042 *	.1853	-.7143 *	-.1441	-.7092 *	-.0187
Back Standard Deviation	-.8524 **	-.1482	-.7857 *	-.0360	-.7092 *	-.2433
Back Ratio Maximum	.2431	.6671 (a)	.3604	.0721	.3119	.6736 *
Back Ratio Minimum	.3336	.7106 *	.3929	.4455	.3455	.8780 **

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

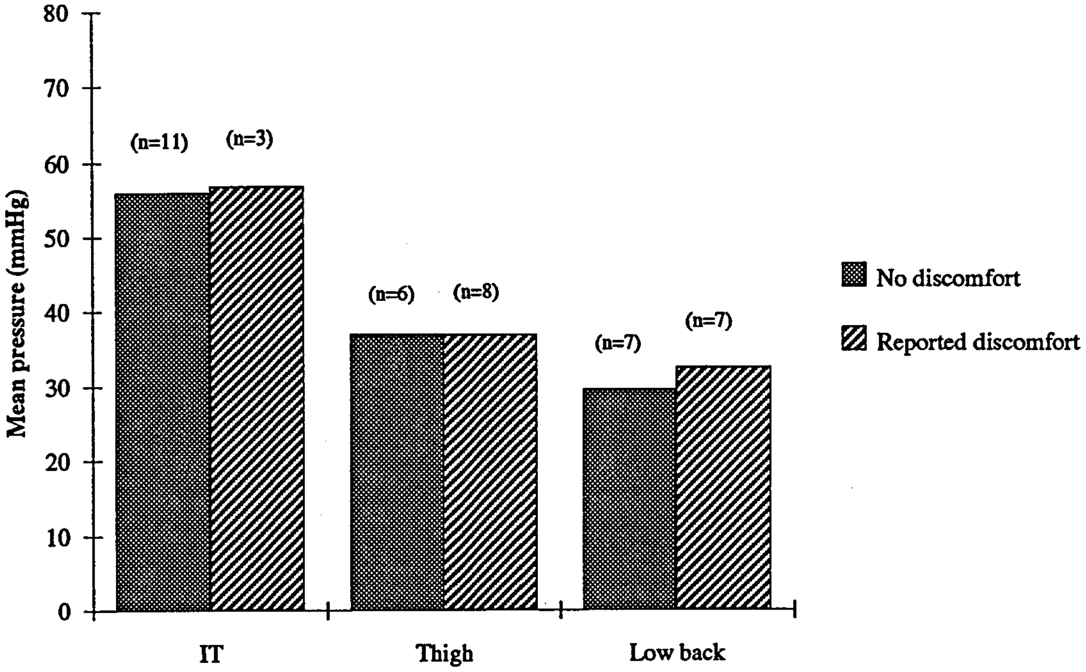
Mean pressure values (maximum, mean, proportion, cell total, maximum ratio, minimum ratio) for the IT area, thigh area and low back, under both conditions were then compared for those who experienced discomfort (total minutes, mean rank, rating after 135 minutes) with those who experienced no discomfort. Males and females were considered together as one group for statistical analysis to be carried out. Altogether 78 Mann-Whitney tests were conducted, but no significant differences in pressure were found between the groups that experienced discomfort and those that did not. Figure 40 is one illustration of this and shows that with the least preferred seat there were very similar mean pressures between the IT, thigh and low back areas despite reported discomfort. With the preferred seat there was a trend (not significant) for higher mean IT pressures in subjects who experienced no discomfort in the IT and low back areas. However in the thigh area, the mean pressures were higher for subjects who reported discomfort.

11.4.8 Interrelations Between Subjective Observations and Subjective Predictions of Hardness and Interface Pressure

The initial analysis was concerned with the relationship between pressure and discomfort with the least preferred seat. It was noticed for most subjects that the least preferred seat was the harder seat and in most cases the hardest of those available for selection. In order to further explore the pressure data it was therefore decided to define the subject group to consist of those whose least preferred seat was actually made of harder foam in the IT (n=11), low back (n=11) or thigh (n=12) areas. In this way the analysis was now concerned with the relationship between pressure values and the hardest and least preferred seat. It was expected that the analysis would find more consistent relationships if they existed. The pressure values of the modified group are given in Table 62.

Figure 40. Mean pressure values for the preferred and least preferred seats according to discomfort after 135 minutes in the IT's, thighs and low back.

Least preferred seat (n=14)



Preferred seat (n=14)

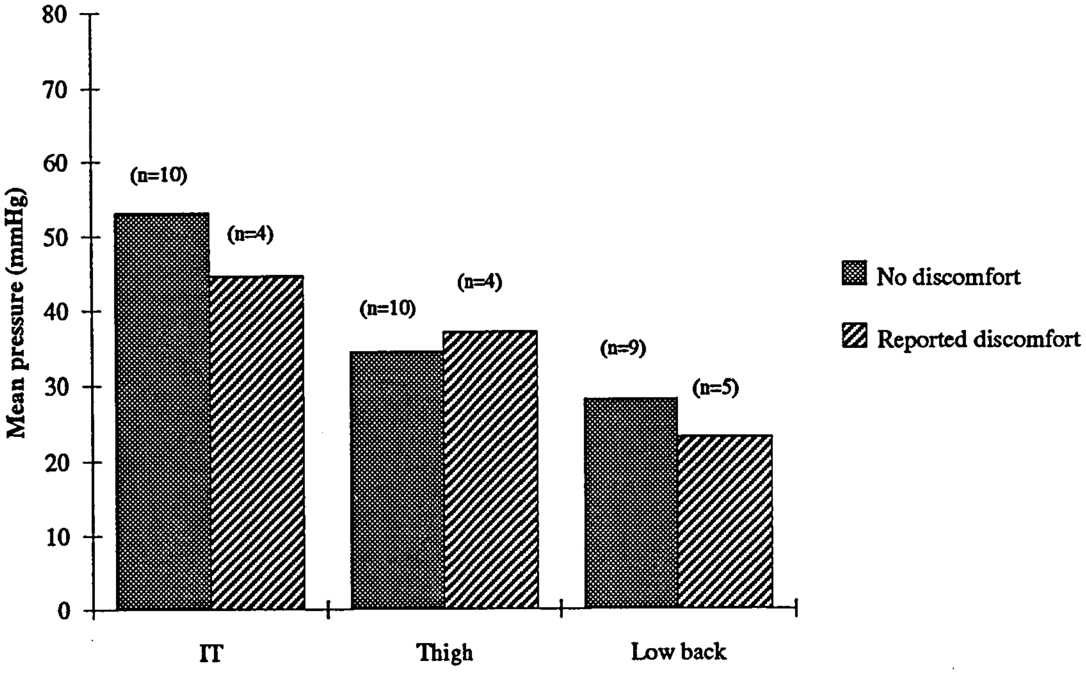


Table 62. Pressure values and significant differences between preferred and least preferred (harder) seats (n=11 or 12).

	Males			Females		
Pressure value	**Preferred Seat**	**Least Preferred Seat**	**Sig.**	**Preferred Seat**	**Least Preferred Seat**	**Sig.**
Low back		(n=6)			(n=5)	
Mean	30.3 (4.5) 22-34	37.5 (11.5) 26-58	NS	23.7 (3.9) 19-29	27.5 (7.8) 19-35	NS
Maximum	65.7 (31.4) 33-111	72.3 (40.2) 37-125	NS	36.8 (8..4) 25-47	50 (19.6) 27-68	NS
Sum of cells	683 (163) 439-866	904 (280.8) 475-1279	*	564 (176.9) 377-848	675 (347.4) 260-1071	NS
Right IT		(n=6)			(n=5)	
Mean	58.2 (6.6) 53-69	65.5 (11.4) 49-79	NS	45.2 (4.2) 40-51	49.5 (6.1) 42-56	NS
Maximum	86.7 (18.8) 64-109	98 (23.1) 75-130	NS	63.4 (15.6) 52-90	74.2 (16.5) 54-88	NS
Sum of cells	524 (59.2) 475-622	589 (102.5) 437-709	NS	407 (37.8) 363-455	445 (54.7) 378-504	NS
Proportion of seat area	0.26 (0.02) 0.22-0.33	0.3 (0.02) 0.28-0.34	*	0.23 (0.02) 0.22-0.26	0.27 (0.02) 0.24-0.3	*
Right Thigh		(n=6)			(n=6)	
Mean	35.6 (5.9) 27-45	38.4 (5.8) 31-47	NS	29.8 (3.8) 26-36	29.8 (5.8) 25-39	NS
Maximum	44.8 (8.5) 30-54	52.3 (9.5) 38-64	**	39.2 (3.8) 35-45	39.2 (7.9) 30-52	NS
Sum of cells	285 (47.5) 215-356	307 (46.5) 250-372	NS	238 (30.5) 208-286	239 (46) 196-310	NS
Proportion of seat area	0.15 (0.03) 0.11-0.17	0.16 (0.03) 0.13-0.19	NS	0.14 (0.02) 0.11-0.17	0.15 (0.02) 0.12-0.17	NS

N.B. NS = Not significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

The Seat Detail data sheets (observed and predicted) from the questionnaire (Appendix 14) were then used to obtain two groups of subjects for comparison, those who subjectively judged the seat was too hard and those who judged the seat was just right in the IT (letter K), thigh (letter M) and low back (letter G) areas. The mean pressure values (maximum, mean, proportion, cell total, maximum ratio, minimum ratio) for these groups were then compared for both conditions.

Out of 76 Mann-Whitney tests there was only one significant result and three approaching significance. These were as follows:-

1. A higher IT mean and maximum (K) was associated with those who predicted the seat to be too hard at the beginning of the trial, in the IT area under the least preferred seat condition ($0.1>p>0.05$).
2. A higher thigh maximum (M) was associated with those who predicted the seat to be too hard at the beginning of the trial in the thigh area, under the preferred seat condition ($p<0.05$).
3. A larger thigh maximum ratio (M) was associated with those who observed the seat to be too hard at the end of the trial in the thigh area, under the preferred seat condition ($0.1>p>0.05$).

11.4.9 Interrelations Between Subjective Observations and Subjective Predictions of Hardness and Discomfort

The same subjects as defined in Section 11.3.8 were once again divided for comparison according to subjects who judged the seat as being too hard and those who judged the seat as just right in the IT, low back and thigh areas. This time the comfort variables were compared (mean minutes, mean rank and rating after 135 minutes) between the two groups.

Predictions of hardness made after 15 minutes in the IT and low back areas (based on the Seat Detail data sheet, Appendix 14) were not consistent with increased discomfort in these areas. However more discomfort was reported in the IT area by subjects who observed that the least preferred seat was too hard in this area at the end of the driving simulation (Table 63). Predictions of hardness in the thigh area were more consistent. Subjects who predicted that the seat would be too hard in the thigh area reported more discomfort (Table 64), but with the preferred (softer) seat only. In this instance, however, observations of hardness at the end of the trial were not consistent with discomfort. Observations of hardness in the low back area were also not linked to reported discomfort.

Table 63. The reported IT discomfort of subjects who observed the seat to be too hard or just right in the IT area with the least preferred (harder) seat.

	Seat observation - Too hard Mean (SD), Range, (n=5).	**Seat observation - Just right** Mean (SD), Range, (n=6).	**Significance**
Mean minutes discomfort	54 (61.48), 0-120	0	*
Mean discomfort rank	4.6 (.84), 4-5.7	2.8 (1.01), 1-4	**
Discomfort rating - 135 minutes	5 (1.41), 4-7	3 (1.09), 1-4	*

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 64. The reported thigh discomfort of subjects who predicted the seat to be too hard or just right in the thigh area with the preferred (softer) seat.

	Seat prediction-Too hard Mean (SD), Range, (n=4).	**Seat prediction-Just right** Mean (SD), Range, (n=8).	**Significance**
Mean minutes discomfort	75 (86.6), 0-150	15 (42.43), 0-120	NS
Mean discomfort rank	4.35 (.7), 4-5.4	2.8 (1.14), 1-4	*
Discomfort rating - 135 minutes	4.75 (.96), 4-6	3.38 (1.19), 1-5	(a)

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

11.4.10 Multiple Regression Analysis

The technique of multiple regression analysis was used to further explore the whole data set. If IT, thigh or low back discomfort were the dependent variables it was not possible to build a regression model because the independent variables for example body build (RPI), height and interface pressure had a negligible effect i.e. less than 1% of the variance could be explained. It was therefore decided to use the technique to investigate the important variables in predicting interface pressure (IT, thigh and low back). Only the data from experimental condition of 'least preferred seat' was used as subjects actually reported some discomfort. The mean pressure values from the IT, thigh and low back were used, as they were thought to be the most stable measure i.e. least prone to measurement error. A decision was once again made that if possible the data would not be transformed in any way in order to simplify the interpretation of the results.

The data from the 'least preferred seat' experimental condition with mean IT pressure as the dependent variable was considered first. Regression diagnostics (Cook's distance, normal probability plots, standardised residual plots, standardised scatterplot and leverage) were once again used to identify possible outliers or points of influence. Subject 5 was identified as being unusual as she was very overweight (105 kg). Her removal from the data set greatly improved the quality of the data with regard to meeting the assumptions for multiple regression analysis, giving more confidence in the regression coefficients. A multiple correlation table was then produced with mean IT pressure (the dependent variable) and age, gender, body build (RPI), anthropometric data, postural angles and IT discomfort (the independent variables). A statistical approach based on adjusted r-squared was used to decide the 'best fit' to the model. The best model (without subject 5) explained 43.02% of the variance, with the variables sex and hip breadth (Table 65). The low VIF values (1.024 and 1.024) indicated no problems with multicollinearity. If subject 5 was included in the data 46.58% of the variance was explained in the model, therefore her effect on the regression model itself was small. The justification in removing her from the data sample allowed more confidence in the regression equation itself.

Table 65. Variables entered into the multiple regression equation for 'best fit' of the model for the 'least preferred seat' experimental condition (n=13). The dependent variable was mean IT pressure.

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
Sex	.3249	.0246	-12.1836	4.8087	1.024	
Hip Breadth	.4302	.1023	-.2176	.1249	1.024	154.2638

It was then attempted to explore the important variables in predicting thigh and low back discomfort, however using the statistical approach based on adjusted r-squared, it was not possible to form a multiple regression equation. The best model for both the thigh and low back separately explained less than 1% of the variance.

11.5 Discussion

The method of paired comparisons

In this static showroom style analysis, the preferred seat cushion, backrest, overall seat and the two least preferred seats agreed with the pilot trail (Figures 35 and 36), validating this as a reliable technique for selecting the 'best' and the 'worst' from a range of visually identical car seats. The sensitivity of the test for accurately ranking all seven production range foams for the seat cushion, backrest and overall seat however must be questioned. It must also be noted that for both this trial and the pilot trial subjects preferred separately the seat cushion and backrest for seat 3, although the preferred seat overall was seat 4. It appears that some subjects only liked either seat 3 cushion or backrest in any pairing, but overall seat 3 was least preferred in some pairings.

In order to fully validate this as a predictive method, all seven experimental seats should be assessed on extended driving simulations / road trials and compared to the ranked order obtained.

Discomfort

Subjects were sat in their optimum postures under both experimental conditions. It was expected that the larger driving workspace created by the optimum posture, would allow greater freedom of movement for both males and females, important in the avoidance of discomfort (Akerblom 1948 cited by Keegan, 1953; Kramer, 1973 and Rebiffe, 1980), but that the least preferred, harder seat would cause more discomfort. This was the case for males but not for females. There was a trend in males for reported discomfort in more body areas with the least preferred seat (as selected by the method of paired comparisons), significantly so in the buttock and thigh areas. There was very little difference in reported discomfort between the two seats in females. Differences regarding discomfort for each time period between gender were not significant with the exception of neck discomfort which was reported by more females. The order presentation of either the selected 'preferred' or 'least preferred' seats on the driving rig was balanced in obtaining the subjects' optimum posture from the method of fitting trials. It was therefore unlikely that an incorrect optimum posture was the cause of more reported discomfort under the least preferred (harder seat) in the taller males. It could just be that males were sensitive to the higher, but not significantly different pressures resulting from the least preferred seat. For example, a mean IT pressure of 63.7 (SD 11.5) compared with 57.3 (SD 6.4). Although the subject numbers were too small for validation, it could also be that these results add strength to the idea that posture (including the ability to vary posture) is more important than a good seat in reducing driver discomfort. Females reported similar discomfort under both conditions, despite obvious differences in foam hardnesses.

It can also be seen clearly that discomfort increases over time, warning of the dangers of forming conclusions based on driving studies of 15 / 20 minutes as unfortunately still found in the literature such as Lee and Ferraiuolo (1993), Shen and Galer (1993) and Gross et al (1994). For example, after 15 minutes of the experiment with the least preferred seat no males reported right buttock discomfort compared with 29% after 135 minutes.

Interface pressure

There was a trend for higher pressures with the least preferred seat for both males and females for the thigh, buttock and low back areas. The difference between the preferred and least preferred seat was significant ($p<0.05$) for the 'proportion of seat area' taken by the right IT, with a greater proportion recorded for the least preferred seat for both males and females separately. The actual values for this difference, however, were very small. For males 3% more pressure was taken under the right IT sat in the least preferred seat and for females this figure was 4%.

Agreeing with Yang et al (1984) and Zacharkow (1988), there was a trend for males to have higher pressures than females, significantly so ($p<0.05$) under the IT area with a mean pressure of 63.66 mmHg (SD 11.45) for males, compared with 48.85 mmHg for females (SD 6.33), for the least preferred seat condition. Agreeing with Garber and Krouskop (1982), thinner subjects (higher RPI) also had higher pressures under the IT area. For example, two males with Reciprocal Ponder Indices of 45.1 and 39.6 respectively had mean IT pressure values of 63.2 and 52.1 mmHg (more than 10 mmHg difference). Whereas heavier subjects (defined by weight) had significantly higher thigh pressure values. For example, a female weighing 105 kg had a mean thigh pressure of 51.9 mmHg, compared with a female weighing 47.5 kg with a mean thigh pressure of 26.4 mmHg. However, in the same study by Yang et al (1984), no relationships were found between interface pressure and weight, body build or height. It could be that the small ranges of height (1450 - 1720 mm) and weight (42 - 79 kg) in their study were not enough for strong correlations. In the study by Holley et al (1979) there were also no correlations between interface pressure measurement and weight, and gender differences were not mentioned. Rather than the crude measures of body build (RPI), weight and height, it is possible that seated skin, fat and muscle thicknesses and IT size may show stronger correlations with interface pressure, but obviously these measurements are not easily obtained.

The relationships between posture and the pressure values for each seat were not consistent. However, there was a repeatedly observed, negative relationship, between ankle angle and IT pressure i.e. as ankle angle increased IT pressure values decreased. This was more likely to be due to the fact that as subjects depressed the accelerator the concentration of pressure shifted from the IT area to involve the thigh area. Other studies have shown pressure changes with different postures but only under carefully controlled experimental conditions. For example, Shen and Galer (1993) found that six changes in angle of an experimental chair were reflected in the subsequent pressure readings.

Despite extensive manipulation and statistical testing of the data, correlations between interface pressure and discomfort were not consistent. The only significant correlations (negative) were between low back pressure variables and discomfort for females using their preferred seat. It could be that there was not adequate support in the low back area for females with this seat and this accounted for the lower pressures and discomfort. However, there was only 3 mmHg difference between the mean back pressures for the preferred and least preferred seat conditions (23.3, SD 3.7 compared with 26.8, SD 8.1). Mann-Whitney tests were then conducted to explore whether subjects who observed or predicted hardness of the seat in the IT, thigh and low back areas had different pressure values, but out of 76 tests there was only one significant result and three approaching significance. It must therefore be concluded that the results of this particular analysis probably occurred by chance. Critical appraisal of the literature does not support the conclusion that there is a simple relationship between discomfort and pressure. Many of the studies reviewed in Chapter 8.4.4 were unclear with regard to reporting their results or they were based on short term discomfort evaluations / predictions or with small numbers of subjects. Many of these studies concluded that further analysis or study was required.

Mann-Whitney tests were also conducted to find out if subjects who observed or predicted an area of the seat to be too hard actually reported more discomfort in that area of the body in contact with it. Perhaps unsurprisingly subjects who observed (but not predicted) the seat to be too hard in the IT area after the 2.5 hour driving simulation reported more discomfort in this body area, but only for the least preferred seat condition. Conversely predictions (but not observations) of seat hardness in the thigh area were consistent with higher pressures but in this instance only for the preferred seat. It must therefore be concluded that the results of this particular analysis were also unclear.

Multiple regression analysis selected the variables of sex and hip breadth as being the best predictors of mean IT pressure using this data set, with gender having the most influence on the equation. Subjects who were male or had a smaller hip breadth had higher mean IT pressure values. Confidence can be placed in the significant influence of these two variables on mean IT pressure values because the data met the assumptions for this analysis and there was no problem with multicollinearity. The strong influence of the variable sex, agrees with the other analyses and the work of other authors as previously discussed. The combined effect of the variables sex and hip breadth has not been investigated in the literature.

11.6 Conclusions

1. The method of paired comparisons was shown to be a reliable technique for obtaining preferred and least preferred seats with regard to short term, 'showroom' comfort, from seven visually identical, production range foam, car seats. In order to validate this technique as a predictive method for longer periods of driving, studies comparing the rank order of seats obtained with driving simulations or road trials are required.

2. Reported discomfort clearly increases over time and the subsequent classification of seats as 'best' or 'worst' is time dependent. Care must be taken with the results of all evaluations of car seats, based on short time periods.

3. There was a trend for higher pressure values with the least preferred seat for both males and females, although differences in the actual values were small.

4. The pressure values for males were significantly higher than those for females in the IT, thigh and low back areas. Gender and hip breadth were the best predictors of mean IT pressure, with the result that males and subjects with a smaller hip breadth produce higher IT pressure values. Thinner subjects had significantly higher IT pressures while heavier subjects had significantly higher thigh pressures.

5. No consistent significant relationships were found between interface pressure variables and posture with the exception of ankle angle and IT pressure values. In the literature it was only under controlled experimental conditions that such relationships existed.

7. Disappointingly, subjects' predictions (and even observations) of seat hardness did not match areas of higher pressures or areas of reported discomfort in the car seat, even with the least preferred seat condition.

8. a) Discomfort was more frequently reported with the least preferred seat driving condition but for males only. For this group only, significantly more minutes of discomfort were reported in the right buttock and thighs. The differences between the two seat conditions in the pressure values for these body areas in males were not significant, but there was a trend for higher pressures with the least preferred seat.

   b) Also, the only consistent relationships between the pressure variables and the discomfort variables were for females only, with their preferred seat. In this instance there were consistent, significant, negative correlations between the low back pressure variables and discomfort variables, i.e. discomfort ratings were lower as pressure increased. Although the mean low back pressure was only 3 mm Hg higher with their least preferred seat, no such relationship with discomfort existed with this seat.

   In view of points a) and b), the simple analysis of interface pressure data using the assumption that high (or low) pressure values are predictors of increased discomfort still lacks clarity as an approach, based on this experimental situation.

The final discussion and conclusions regarding this work are presented in Chapter 13 together with those for Experiments 1 and 3.

Chapter 12 Experiment 3 - Fixed seat: Comparison of a Limited and Fully Adjustable Driving Package

12.1 Introduction

Following on from Experiment 2 it was apparent that the relationships between interface pressure data, reported discomfort and posture were unclear, under the conditions of looking only within a production variance of foams with subjects sat in their optimum postures. This indicated that the simple use of interface pressure values for the prediction of car seat discomfort was not satisfactory.

In this study it was decided to hold the seat design constant, but to vary posture within subjects and between subjects, by comparing a limited driving package (taken from a well known car) with a fully adjustable driving package. In this way posture would vary within realistic constraints. In an attempt to ensure that there was some reported discomfort, subjects were selected who represented the extremes of anthropometric dimensions i.e. the very tall and the very short. These subjects also represented the group of individuals who may have problems with a standard driving package being close to or outside the normal range of design criteria. The same objective and subjective methodologies were explored as with the previous study. The experimental rationale is explained more fully in Chapter 8.5.

12.2 Experimental Procedure

Sessions once again involved a fitting trial and a repeated measures design whereby two medium term static driving trials were completed by 12 carefully selected subjects. Environmental and procedural conditions were held constant. Under close supervision of the author, a final year ergonomics student was the experimenter for eight of the subjects. The other experiments and all of the data analyses were carried out by the author. Subjects were all university students and therefore fairly homogenous in age and driving experience. They received payment for their time. They also had no musculoskeletal troubles during the last year. Again they were instructed to wear clothing which was not too bulky but which was comfortable for driving. It was also important that their clothing had no heavy seams, buttons or pockets in order that there was a minimal effect on the interface pressure readings. They were asked to wear shoes which they would normally wear for driving.

Age and gender

The sample consisted of six males with a mean age of 20.8 years (SD 1.3) and six females with a mean age of 21.2 years (SD 2.6).

Anthropometric data

Subjects (6 males and 6 females) were selected to represent both ends of the percentile range of anthropometric dimensions related to sitting posture for example leg length, arm length and sitting height. It was felt that these subjects were those most at risk from experiencing problems with current car workstation layout and represented extremes in design. As can be seen in Table 66, the sample selected generally represents both ends of the UK adult population (Pheasant 1990b) for stature, weight, buttock knee length, knee height and upper limb length, although subjects with large hip breadths and short sitting heights were not represented.

N.B. Table 66 also shows the Reciprocal Ponder Index which was the measure of body build calculated.

Table 66. Anthropometric data by gender for Experiment 3.

	Males (n=6)		**Females (n=6)**	
	Mean (SD), Range	**Percentile**	**Mean (SD), Range**	**Percentile**
Stature (mm)	1939 (84), 1862-2070	95th-99th+	1543 (22), 1518-1578	7th-30th
Weight (kg)	80 (9), 71-94	37th-95th	52 (5), 45-59	6th-37th
Sitting height (mm)	993 (35), 954-1038	89th-99th+	831 (8.5), 822-842	21st-41st
Buttock knee length (mm)	675 (18), 659-708	98th-99th+	529 (17), 512-557	3rd-11th
Knee height (mm)	604 (41), 559-670	67th-99th+	474 (13), 453-490	4th-36th
Hip breadth (mm)	342 (16), 318-361	8th-51st	319 (31), 285-357	1st-46th
Upper limb length (mm)	863 (33), 815-900	84th-99th+	670 (27), 637-702	2nd-46th
Reciprocal Ponder Index	47.2 (5.5), 43-59	N/A	41.5 (1.3), 40-41	N/A

N.B. SD = Standard Deviation

12.2.1 Static Driving Trials

Subjects once again used the driving rig for the 2.5 hour static driving simulations with the rig set up for both a fully adjustable and a limited driving package; the seat was held constant for both conditions (seat 4). This was the seat which was found to be consistently preferred by the method of paired comparisons in Experiment 2 and the pilot trial. The method of fitting trials was employed (Chapter 8.2.4) to determine the optimum driving posture and position of the controls for each experimental condition, using the range of adjustments offered. The limited package offered the adjustments of a well known small family car. The same measurement procedures were used as in Experiment 2, i.e. Seat Feature Checklist, predictive seat evaluation, comfort / discomfort charts, postural angles and interface pressure readings.

12.3 Results

The results for males and females under each experimental condition are often presented separately as they represent extremes of percentile values for anthropometric data. The statistical tests carried out were the same as those described in Chapter 11.3 for Experiment 2.

12.3.1 Summary Statistics for Experiment 3

Postural Angles

The optimum posture for each of the two driving packages is shown by gender in Table 67. With the fully adjustable driving package the males chose a more 'open' posture: Arm flexion was significantly greater ($p<0.01$), 30.0 degrees (SD 12.6) compared with 20.3 degrees (SD 8.4); elbow angle was significantly greater ($p<0.05$), 103.3 degrees (SD 14.1) compared with 90.5 degrees (SD 17.7) and trunk-thigh angle was 102.1 degrees (SD 6.4) compared with 94.7 degrees (SD 12.4) which was approaching significance ($0.1>p>0.05$). The posture of females changed very little between the two packages with the exception of elbow angle which was significantly greater with the fully adjustable driving package, 121.5 degrees (SD 23.7) compared with 98.5 degrees (SD 22.2). This was probably due to the ability to adjust the steering wheel position with the fully adjustable package.

Table 67. Postural angles and significant differences between a limited and fully adjustable driving packages.

	Males (n=6) Mean (SD), Range			Females (n=6) Mean (SD), Range		
Posture	**Limited Package**	**Fully Adjustable Package**	**Sig.**	**Limited Package**	**Fully Adjustable Package**	**Sig.**
Neck inclination	23.8 (15.2) 9-49	18.8 (16.5) 8-51	NS	21.5 (16.9) 7-44	18.3 (16.6) 7-47	NS
Trunk-thigh angle	94.7 (12.4) 86-119	102.1 (6.4) 96-112	(a)	101.7 (5.8) 92-108	101.3 (6.3) 94-109	NS
Knee angle	115.5 (7.7) 108-130	120.8 (5.0) 112-125	NS	115.3 (13.4) 99-135	113.8 (11.8) 104-133	NS
Arms (to the vertical)	20.3 (8.4) 7-32	30 (12.6) 8-44	**	35.2 (17.1) 5-54	32.5 (15.0) 7-54	NS
Elbow angle	90.5 (17.7) 79-126	103.3 (14.1) 88-126	*	98.5 (22.2) 76-137	121.5 (23.7) 94-150	**
Foot-calf angle	96.5 (6.1) 90-105	101 (2.5) 98-105	NS	96.8 (7.4) 86-104	95.3 (7.2) 85-105	NS

N.B. NS = Not Significant, (a)=0.1>p>0.05, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Positions of the controls

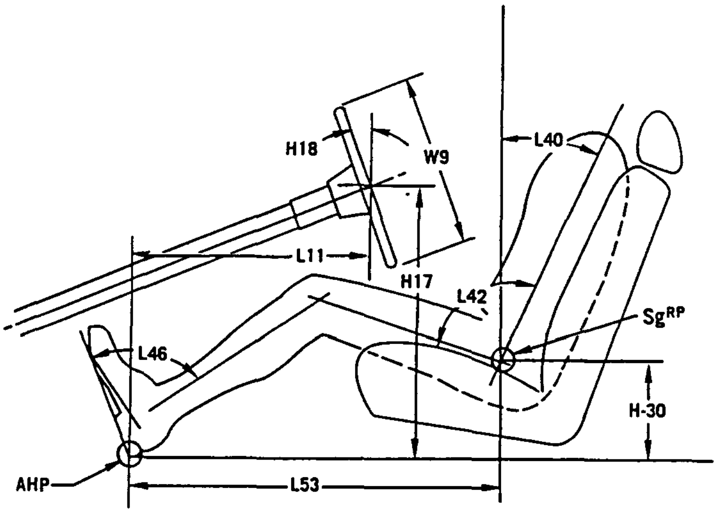
The H-point values (SAE Handbook, 1985) for the positions of the controls for both driving packages are shown in Table 68. The dimensions for the fixed package were taken from a well known small family car. Unfortunately, due to a design limitation in the driving rig it was necessary for slight horizontal adjustment of the steering wheel closer to the body for the females in order to be able to move the pedals closer. This had an effect on the values of L11 and L53-L11. This would not have been the case with the actual car.

Table 68 shows that there was a significant difference between the limited and fully adjustable driving packages for both males ($p<0.001$) and females ($p<0.01$) for the distance of the steering wheel away from the body (L53-L11), such that the steering wheel was positioned further away from the body with the fully adjustable driving package. For females only, the steering wheel was significantly lower ($p<0.01$) in relation to the body for the fully adjustable driving package (H17-H30). These both represent a need for more adjustability in the steering wheel with the limited package.

Table 68. H-point values (SAE Handbook, 1985) and significant differences between a limited and fully adjustable driving package.

	Males (n=6)			Females (n=6)		
H-point	**Limited Package Mean (SD) Range**	**Fully Adjustable Package Mean (SD) Range**	**Sig.**	**Limited Package Mean (SD) Range**	**Fully Adjustable Package Mean (SD) Range**	**Sig.**
H17	650 mm	624 (75.6) 514-748 mm	NS	650 (0.4) 650 mm	604 (33.2) 547-634 mm	*
H30	298 mm	259 (44.5) 177-297 mm	(a)	298 mm	287 (19.3) 254-303 mm	NS
L11	580 mm	496 (20.9) 467-522 mm	***	454 (39.4) 410-509 mm	366 (49.9) 304-429 mm	**
L40	16 (5.6) 11-26 degrees	14 (5.4) 7-20 degrees	NS	15 (3.7) 10-18 degrees	14 (3.3) 10-18 degrees	NS
L42	94 (4.9) 89-103 degrees	94 (3.9) 89-98 degrees	NS	93 (3.3) 88-96 degrees	92 (2.8) 89-96 degrees	NS
L53	851 (9.4) 832-855 mm	869 (36.6) 826-916 mm	NS	658 (34.6) 623-705 mm	630 (26.6) 599-660 mm	NS
H17-H30	352 mm	364 (44.6) 337-452 mm	NS	352 mm	317 (16.2) 293-334 mm	**
L53-L11	271 (9.8) 251-275 mm	372 (23.3) 345-394 mm	***	204 (4.3) 191-215 mm	264 (35.8) 224-307 mm	**

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.



Seat Feature Checklist

Both males and females generally felt that the seat height was adequate for them with both the fully adjustable and limited driving packages. However 50-67% of males reported that both the seat cushion and seat back needed to be longer (but not wider) under the conditions of both driving packages. This was likely to be due to their size. Females were generally happy with the dimensions of both the seat cushion and seat back again under both conditions of the study.

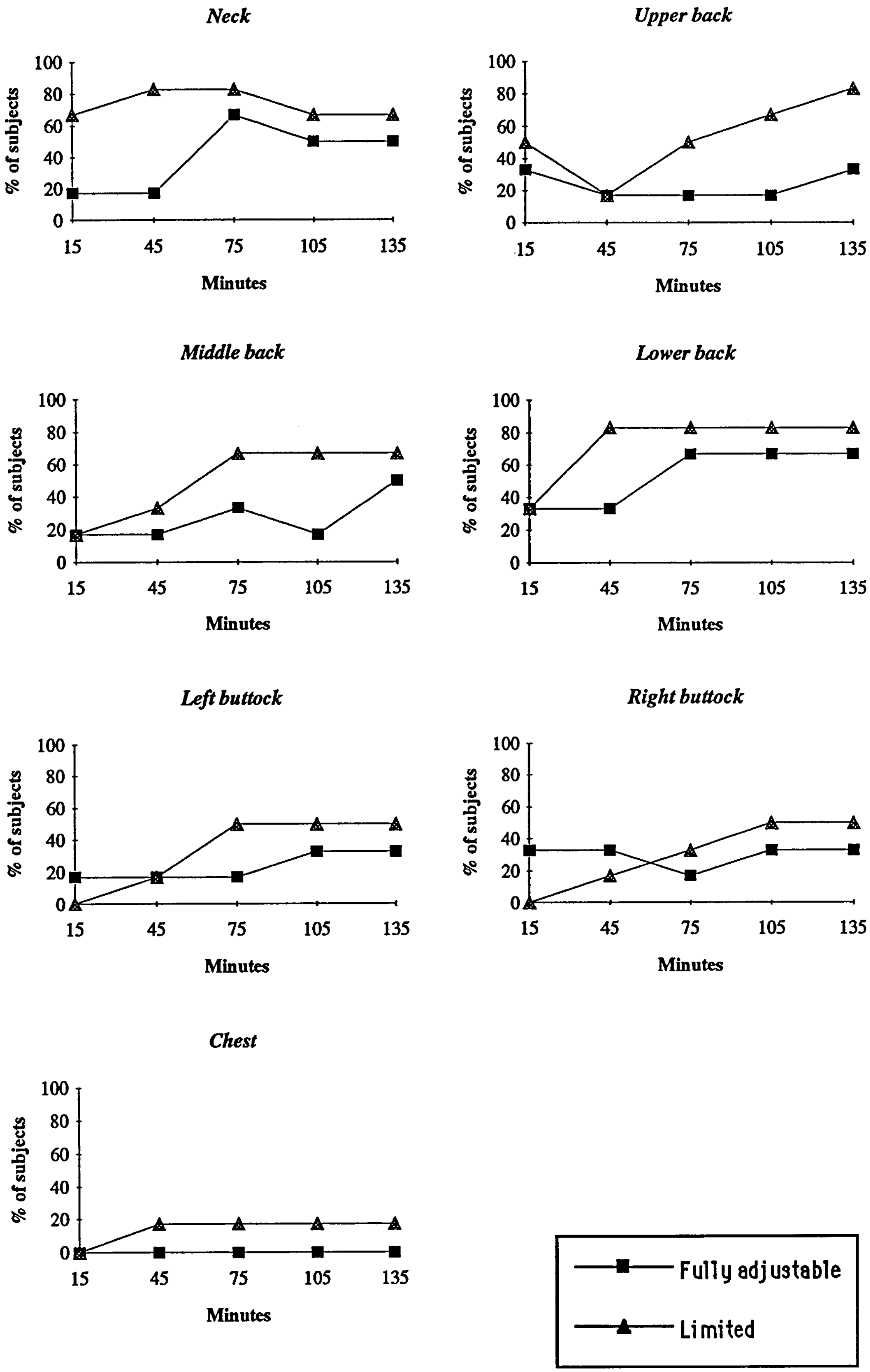
Initial opinions regarding the position of the lumbar support were not clear: Both males and females, despite markedly different anthropometric dimensions, contained subjects who reported that the lumbar support should be higher or lower than existed. The majority of subjects however agreed that the in / out adjustment of the lumbar support was adequate.

12.3.2 Body Part Comfort / Discomfort Charts

The percentage of subjects reporting any discomfort (i.e. those scoring 5, 6 or 7) under both conditions over time are shown for males and females separately in Figures 41 and 42. It can be seen that for males there was a clear trend for a higher frequency of reported discomfort with the limited driving package whereas with females this was not so apparent, except in the case of arm discomfort. The Wilcoxon matched-pairs signed-rank test was used to look at significant differences between the two conditions. Table 69 shows the significant differences for males, the effect being more discomfort with the limited driving package. There were no significant differences in the discomfort reported by females.

Figure 43 shows the mean number of minutes of reported discomfort for each condition and for each body area over the 2.5 hour period. Each of the five comfort evaluations is given a weighting of 30 minutes for each body area giving an overall picture of discomfort. For females there was a trend for more discomfort in the neck, upper back, middle back, lower back, arms and shoulders with the limited driving package. Once again for males discomfort was apparent with the limited package in all body areas. For example, 110 minutes of neck discomfort compared with 60 minutes with the fully adjustable driving package. The sample size was too small for statistical analysis of the different body areas using Wilcoxon's matched-pairs signed-rank test due to the number of tied ranks.

Figure 41. Percentage of males reporting discomfort in different body areas (n=6).



Neck

Upper back

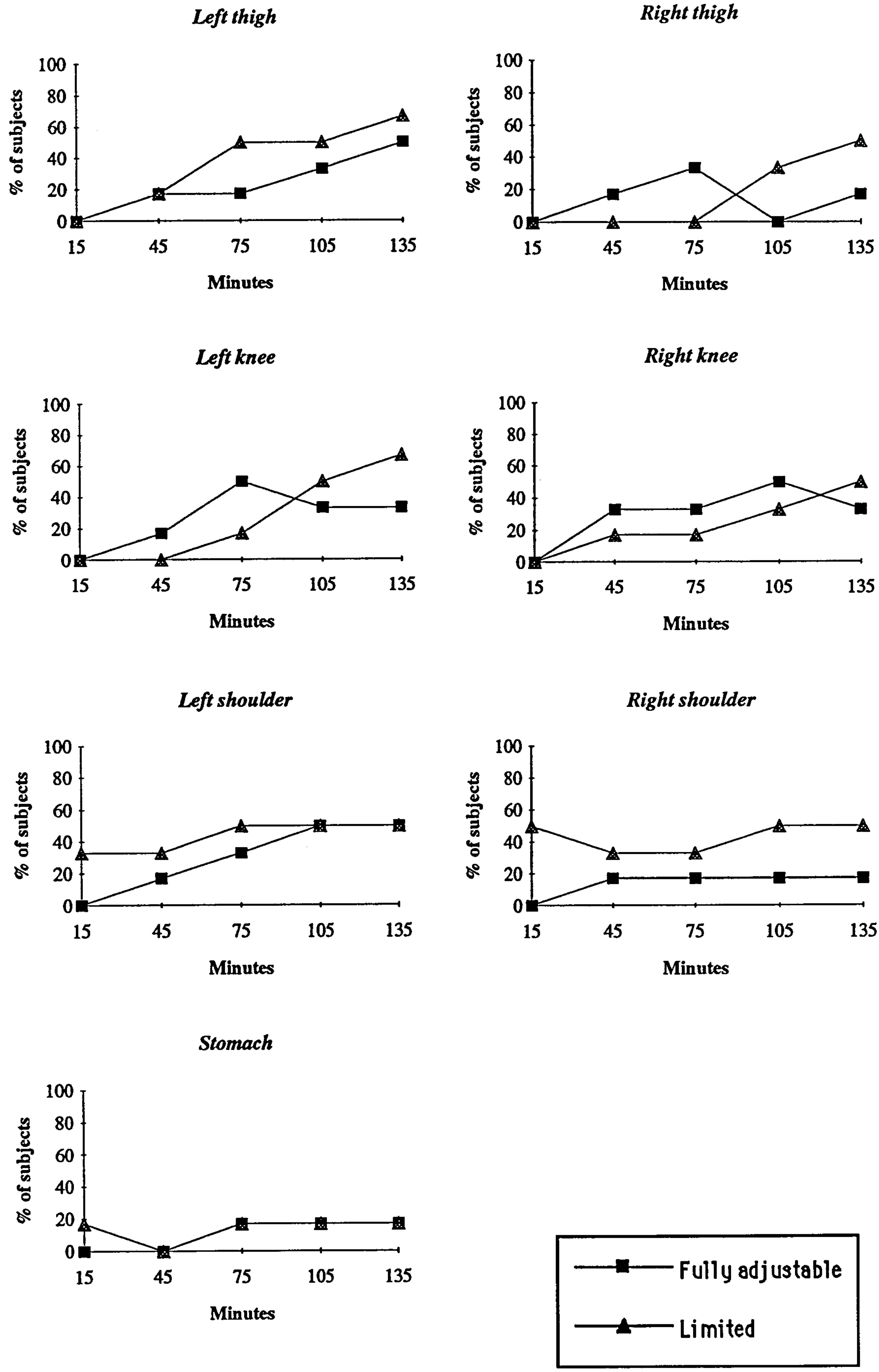
Middle back

Lower back

Left buttock

Right buttock

Chest



Left thigh

Right thigh

Left knee

Right knee

Left shoulder

Right shoulder

Stomach

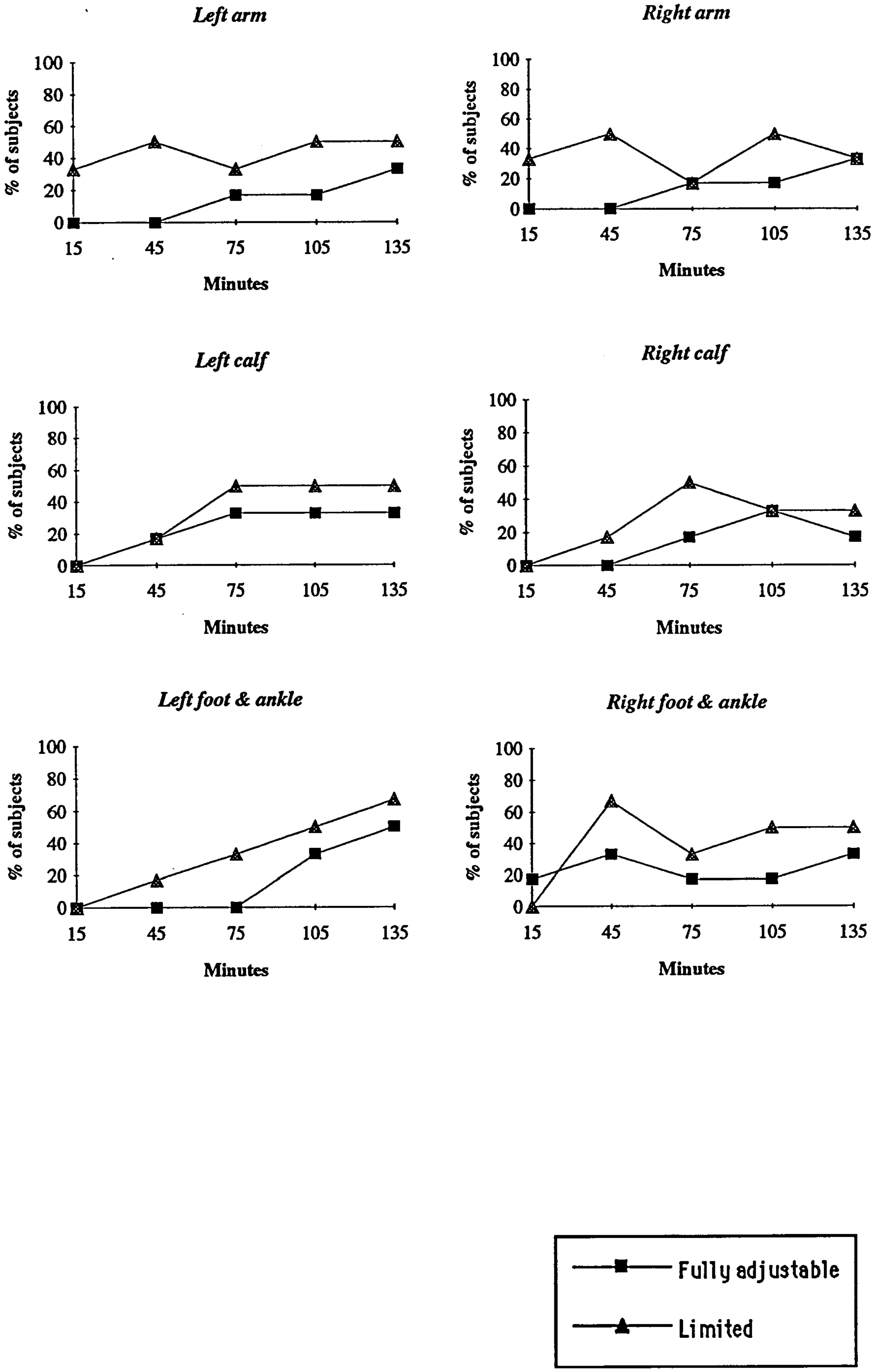
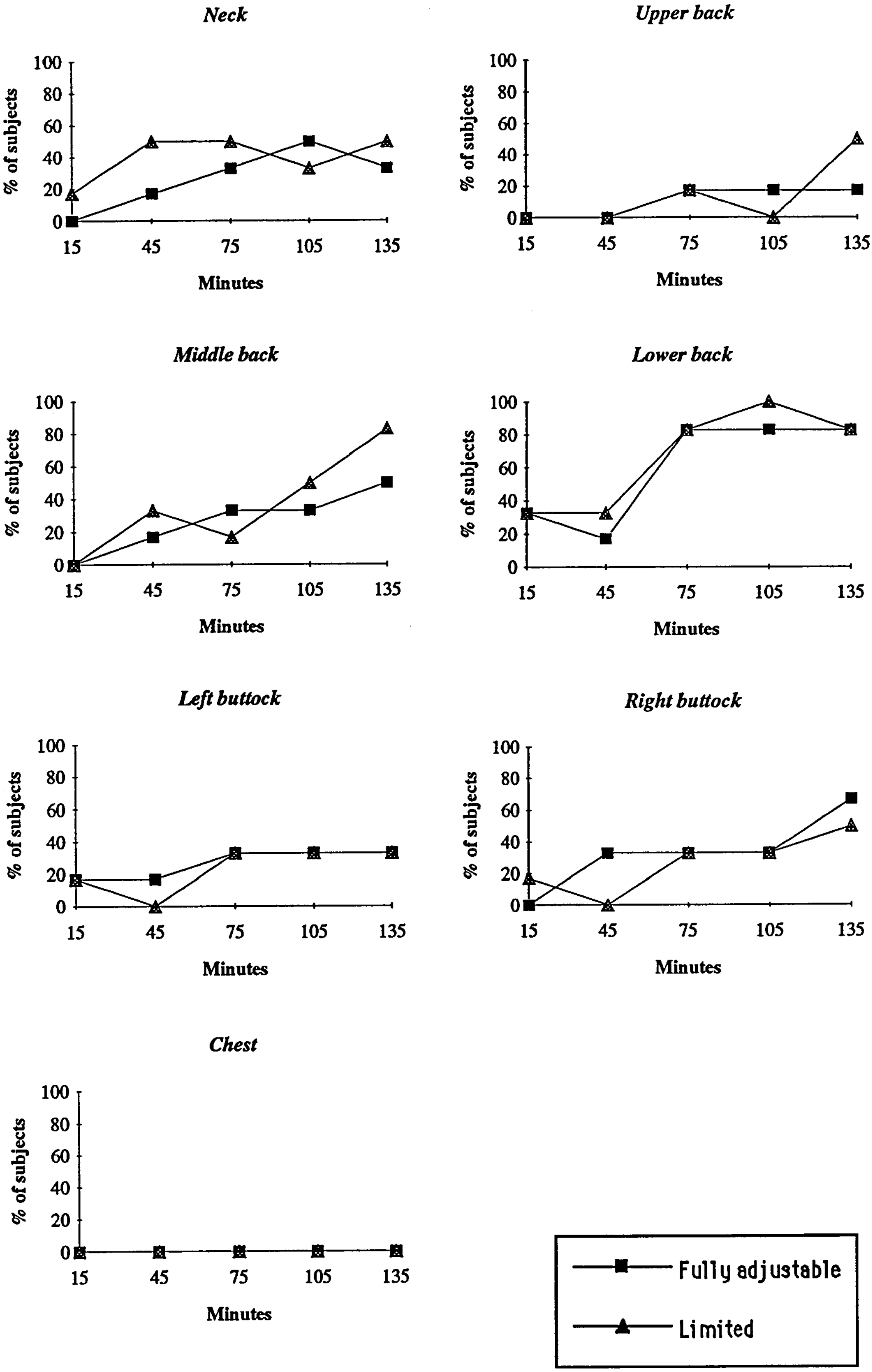
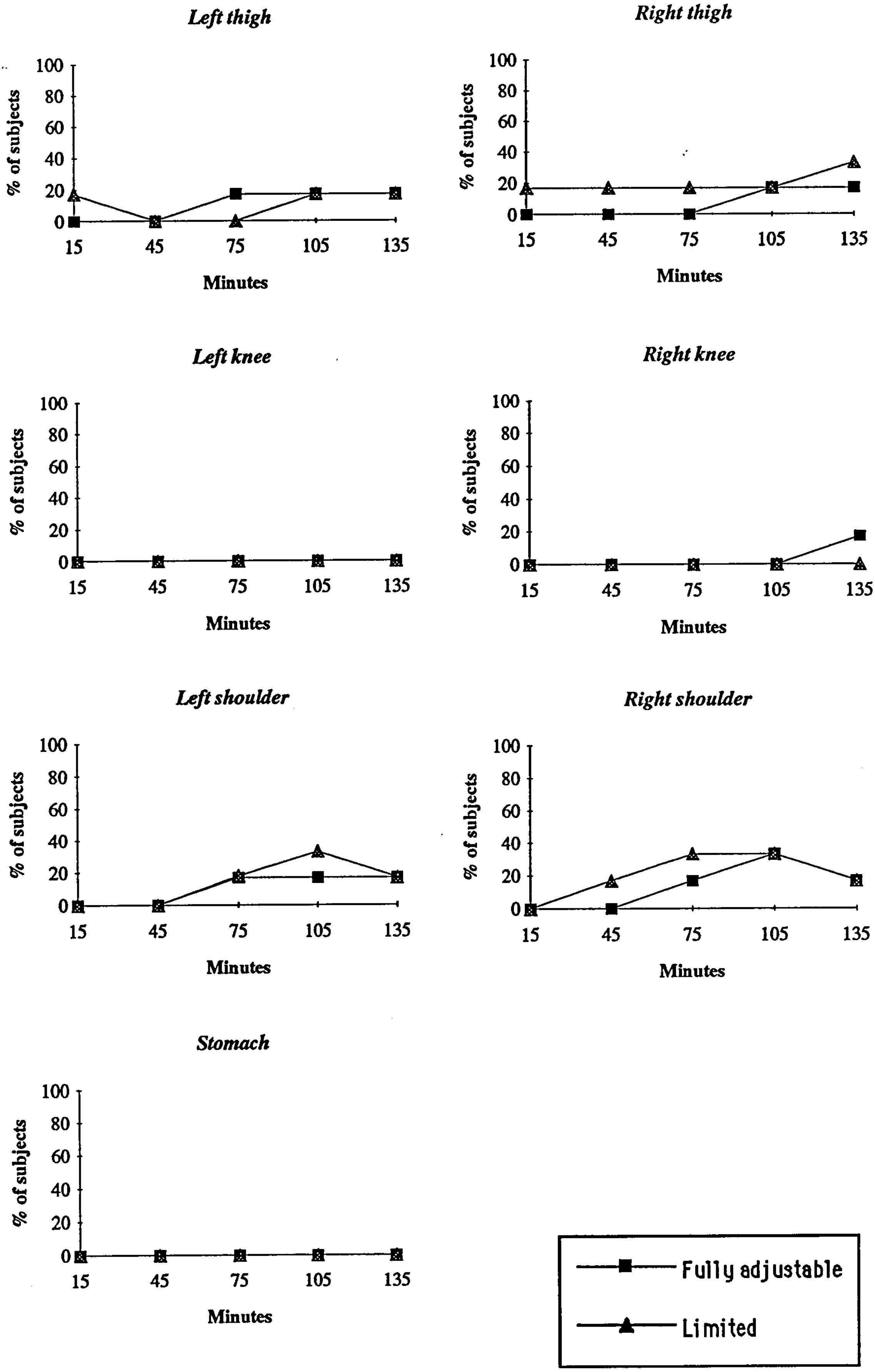

Left arm
Right arm
Left calf
Right calf
Left foot & ankle
Right foot & ankle
% of subjects
100
80
60
40
20
0
15
45
75
105
135
Minutes
Fully adjustable
Limited

Figure 42. Percentage of females reporting discomfort in different body areas (n=6).





Left thigh

Right thigh

Left knee

Right knee

Left shoulder

Right shoulder

Stomach

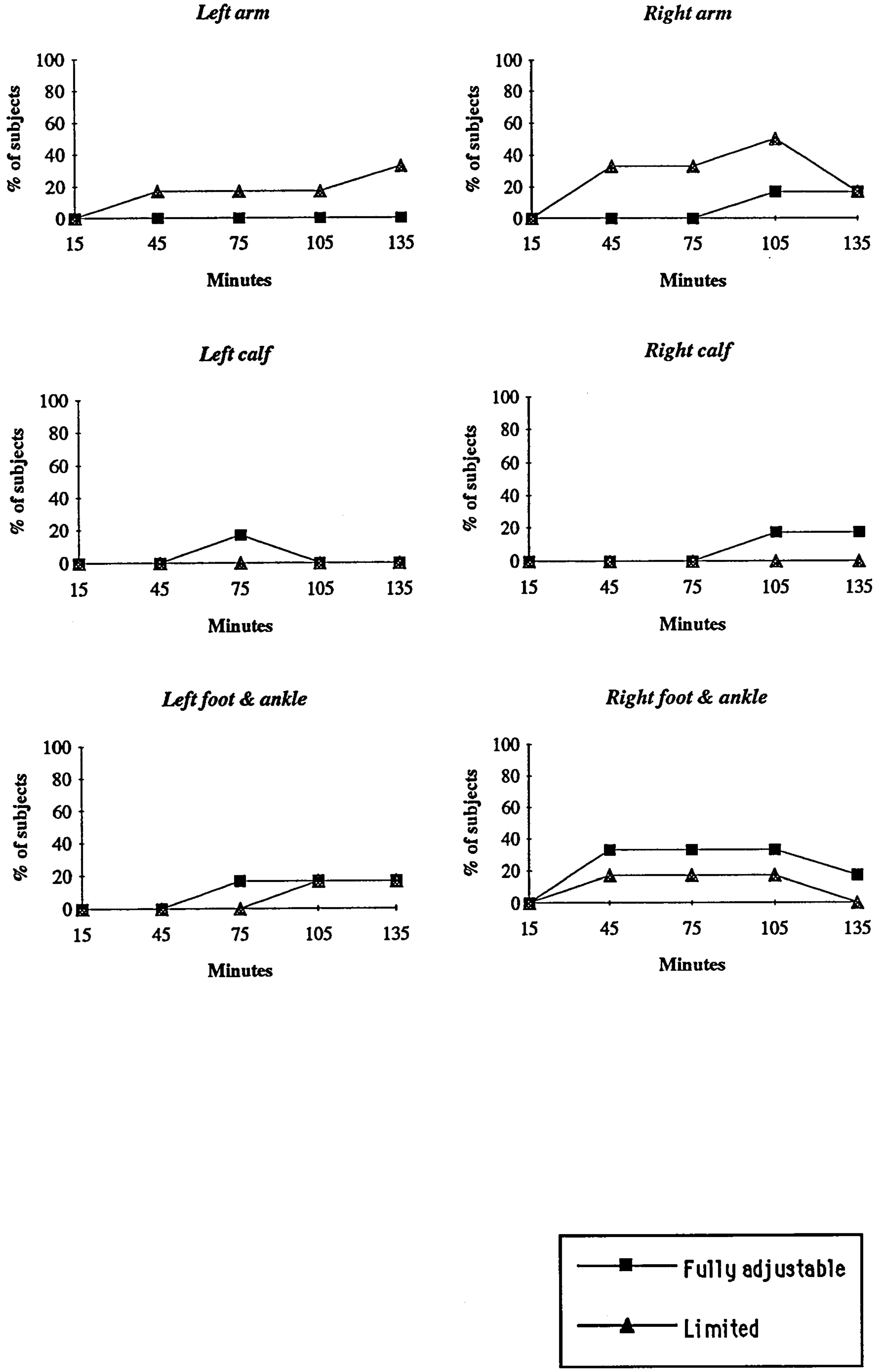
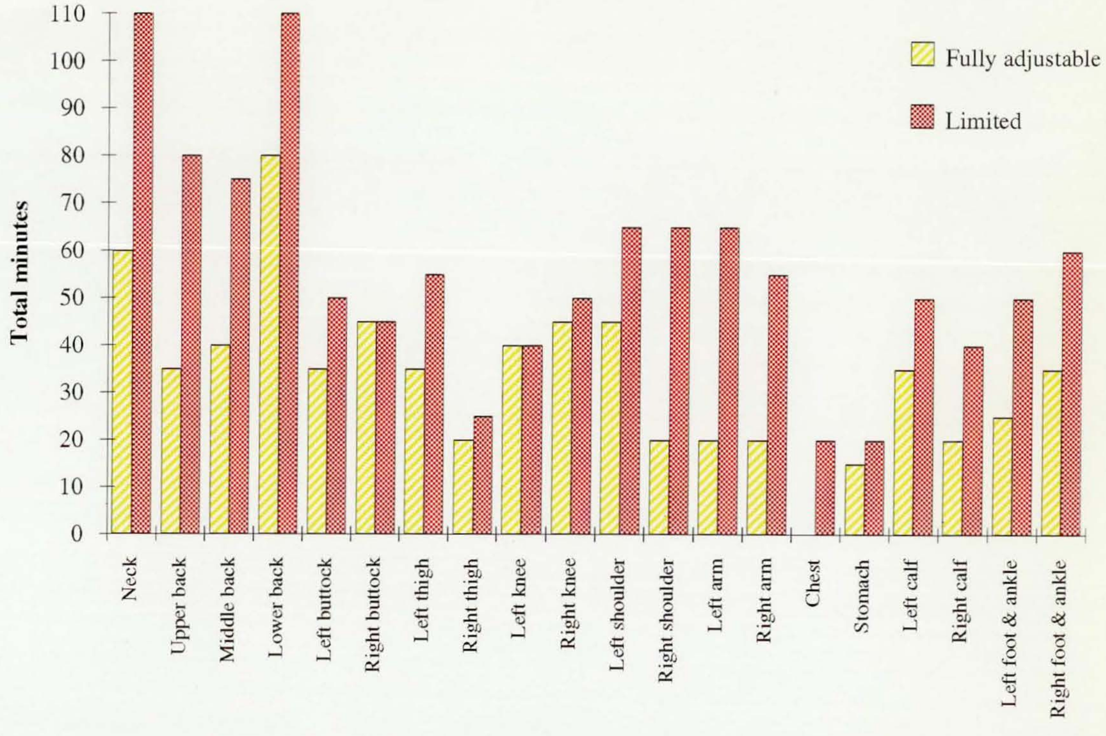

Left arm
Right arm
Left calf
Right calf
Left foot & ankle
Right foot & ankle
% of subjects
100
80
60
40
20
0
15
45
75
105
135
Minutes
Fully adjustable
Limited

Figure 43. Total minutes of reported discomfort (n=12).

Males (n=6)



Females (n=6)

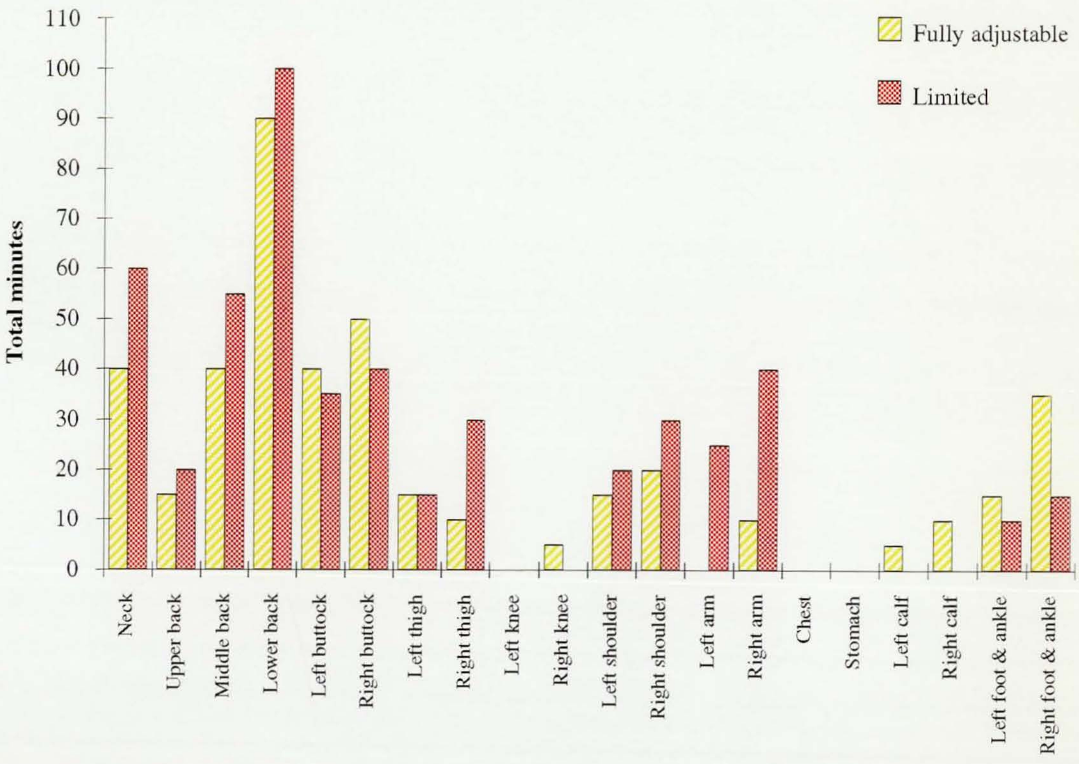


Table 69. Significant results for Wilcoxon matched-pairs signed-rank test comfort / discomfort data (males).

Body part (males)	Time period (minutes)	Significance
Neck	45	(a)
Upper back	105	(a)
Middle back	75, 105	(a), (a)
Lower back	105, 135	(a), (a)
Left buttock	75, 105, 135	(a), (a), *
Right buttock	105, 135	(a), *
Left arm	45	(a)
Right arm	45	(a)
Left knee	135	(a)
Left foot & ankle	75, 105, 135	*, (a), (a)
Right foot & ankle	45, 135, 105	(a), (a), (a)

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

12.3.3 Interface Pressure Descriptive Data

Descriptive data for the right IT, right thigh and low back are shown in Table 70. The reader should once again refer to Appendix 8 for a description of the pressure variables calculated. In the low back there was a trend for higher pressures for both males and females with the fully adjustable package. Under the IT area there were significant differences ($p<0.05$) with pressure variables (mean and sum of cells) for both males and females, the results showing higher pressure readings with the limited driving package. The pressure variables were very similar under the thigh area, between the two driving packages for both males and females. With males a higher proportion of weight was taken by the thigh area with the fully adjustable package, probably due to the more extended posture.

12.3.4 Interrelations Between Gender, Body Build and Interface Pressure

Gender differences

The pressure data revealed significant differences or differences approaching significance between males and females for all of the pressure variables (but one) for the IT and thigh areas under both conditions, the trend being for higher pressure readings in males (Table 71). For example, using the limited driving package mean pressure under the IT area was 75.7 mmHg (SD 21.2) for males compared with 43.9 mmHg (SD 7.2) for females, $p<0.05$. There were no significant differences between males and females for the low back pressure values.

Body build and weight

The Reciprocal Ponder Indices (RPI) for this sample are shown back in Table 66. The correlations between body build (RPI), weight and pressure variables were more consistent than in Experiment 2, probably due to the fact that the sample (n=12) consisted of the extremes in these factors (Table 72). IT pressure variables strongly positively correlated with body build (thinner subjects had higher pressures), whereas weight was a more reliable correlate with thigh pressure values, heavier individuals having higher pressures.

Table 70. Pressure values and significant differences between a limited and fully adjustable driving package (n=12).

	Males (n=6)			Females (n=6)		
Pressure value	**Limited Package**	**Fully Adjustable Package**	**Sig.**	**Limited Package**	**Fully Adjustable Package**	**Sig.**
Low back						
Mean	25.7 (8.8) 12-35	28.9 (6.0) 24-40	NS	21.1 (6.4) 9-27	25.9 (7.3) 17-35	(a)
Maximum	45.3 (16.3) 27-66	53.7 (26.6) 36-107	NS	43.5 (11.9) 26-62	70 (43.6) 23-150	NS
Sum of cells	473.5 (262.9) 164-837	574 (302.8) 306-1162	NS	309.2 (187.5) 94-648	381.8 (173.6) 183-681	(a)
Right IT						
Mean	75.7 (21.2) 54-107	53.7 (7.2) 42-64	*	43.9 (7.3) 33-52	41.3 (6.5) 34-50	*
Maximum	128 (56.3) 71-225	84.7 (17.6) 61-107	(a)	58.8 (15.3) 44-85	60.5 (16.2) 48-91	NS
Sum of cells	681 (190.5) 490-960	483 (65.3) 376-576	*	395.3 (65.6) 300-468	371.8 (58.1) 304-448	*
Proportion of seat area	0.33 (0.09) 0.22-0.45	0.29 (0.05) 0.23-0.34	NS	0.31 (0.06) 0.26-0.42	0.28 (0.09) 0.13-0.39	NS
Right Thigh						
Mean	30.6 (5.0) 23-36	30.9 (1.4) 29-33	NS	25.0 (5.2) 15-29	23.6 (5.5) 17-32	NS
Maximum	46 (9.4) 28-54	42.2 (3.5) 38-47	NS	33.5 (8.4) 20-44	33.1 (3.4) 28-36	NS
Sum of cells	245 (40.1) 187-286	247.6 (11.4) 230-264	NS	199.7 (41.6) 119-232	189.3 (44.4) 138-259	NS
Proportion of seat area	0.12 (0.02) 0.08-0.15	0.15 (0.03) 0.12-0.21	(a)	0.15 (0.03) 0.11-0.19	0.15 (0.04) 0.13-0.22	NS

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 71. Pressure values and significant differences between males and females (n=12).

	Limited Package (n=12) Mean (SD)			Fully Adjustable Package (n=12) Mean (SD)		
Pressure value	**Males**	**Females**	**Sig.**	**Males**	**Females**	**Sig.**
Low back						
Mean	25.7 (8.8)	21.1 (6.4)	NS	28.9 (5.9)	25.9 (7.3)	NS
Maximum	45.3 (16.3)	43.5 (11.9)	NS	53.7 (26.6)	70 (43.6)	NS
Sum of cells	473 (262)	309 (187)	NS	574 (302)	381 (173)	NS
Right IT						
Mean	75.7 (21.2)	43.9 (7.2)	*	53.7 (7.2)	41.3 (6.4)	**
Maximum	128 (56.3)	58.8 (15.2)	*	84.7 (17.6)	60.5 (16.2)	*
Sum of cells	681 (190)	395 (66)	*	483 (65.2)	372 (24)	**
Proportion of seat area	0.29 (.05)	0.27 (.09)	NS	0.33 (.09)	0.30 (.06)	NS
Right Thigh						
Mean	30.6 (5)	24.9 (5.2)	(a)	30.9 (1.4)	23.7 (5.5)	*
Maximum	46 (9.4)	33.5 (8.4)	*	42.2 (3.5)	33.2 (3.3)	***
Sum of cells	245 (40)	199 (42)	(a)	247 (11)	189 (44)	*
Proportion of seat area	0.15 (.03)	0.14 (.04)	NS	0.12 (.02)	0.15 (.03)	(a)

N.B. NS = Not Significant, (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 72. Correlation coefficients (Pearson's r) and significance for body build (RPI), weight and interface pressure for the limited and fully adjustable driving packages (n=12).

Pressure Variable	**Correlation Coefficients**			
	Body Build (RPI)		**Weight**	
	Limited	**Fully Adjustable**	**Limited**	**Fully Adjustable**
Right Ischial Tuberosity (IT)				
IT Maximum	.6339 *	.6657 *	.4895	.4984 (a)
IT Mean	.7482 **	.7760 **	.6210 *	.6528 *
IT Standard Deviation	.5893 *	.4190	.4133	.2941
IT Ratio Maximum	-.5668 (a)	-.1467	-.4078	-.1265
IT Ratio Minimum	-.1567	-.3118	-.3097	-.2694
IT Proportion	.5025	.3675	.0647	.0403
Right Thigh				
Thigh Maximum	.4036	.5393 (a)	.5958 *	.7830 **
Thigh Mean	.3481	.3722	.6982 *	.6565 *
Thigh Standard Deviation	.4713	.0889	.5274 (a)	.1090
Thigh Ratio Maximum	-.4475	.0874	-.3598	.1160
Thigh Ratio Minimum	-.0321	-.2186	-.0209	-.2334
Thigh Proportion	-.3330	-.0537	-.3498	-.0049
Back				
Back Maximum	-.2306	-.2307	.0077	-.2414
Back Mean	.0301	-.0014	.3030	.2227
Back Standard Deviation	-.1876	-.1539	.1090	-.2933
Back Ratio Maximum	.2934	.0320	-.1880	.3284
Back Ratio Minimum	.4629	.2909	.6042	.3237

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

12.3.5 Interrelations Between Posture and Interface Pressure

Once again the relationship between posture and pressure was not clear (see Appendix 17 for correlations). There were also fewer significant correlations possibly due to the fact that with two fairly homogenous groups there was a complete range of postures. The strongest significant relationships were between ankle angle and IT pressure but for males only using the limited driving package. In this instance IT pressure variables (maximum, mean, standard deviation, proportion and gradient) increased as ankle angle increased. These males were in a constrained posture with flexed thighs and therefore were probably only using ankle action to operate the pedals.

12.3.6 Interrelations Between Discomfort and Interface Pressure

The same nine discomfort variables as those for Experiment 2 were calculated for the correlations with the pressure variables. Their calculation is described in Chapter 11.4.7. Once again this had the effect of making the differences between the two driving packages clearer for thigh and buttock discomfort. The variables were as follows for each of the IT, thigh and low back areas:

- Total number of minutes of reported discomfort.
- Mean rank of discomfort
- Discomfort after 135 minutes.

The correlation coefficients are shown in Tables 73 and 74 for males and females separately. There were significant correlations with IT variables and discomfort for males with both the fully adjustable and limited driving package, with the effect that there was more discomfort with higher pressures. This was also true for the thigh area in males, but for the limited package only. Females had significant positive correlations between thigh pressure variables and discomfort, but with the fully adjustable package only.

Table 73. Correlation coefficients (Spearman's rank) and their significance for discomfort and pressure variables with a limited and fully adjustable driving package (males).

Pressure Variable	**Correlation Coefficients (n=6)**					
	Mean Minutes		**Mean Rank**		**135 Minutes**	
	Limited	**Fully Adjust-able**	**Limited**	**Fully Adjust-able**	**Limited**	**Fully Adjust-able**
Right Ischial Tuberosity (IT)						
IT Maximum	.7407 *	.5246	.6179 (a)	.4286	.9258 **	.6179 (a)
IT Mean	.8332 *	.7715 *	.7945 *	.8286 *	.8332 *	.8827 **
IT Standard Deviation	.7407 *	.2777	.6179 (a)	.2571	.9258 **	.4414
IT Ratio Maximum	-.7407 *	.2160	-.6179 (a)	.3714	-.9258 **	.2648
IT Ratio Minimum	.0617	-.2975	.2354	-.0290	-.2469	.0896
IT Proportion	.8454 *	.0636	.8508 *	.1471	.8454 *	.0909
Right Thigh						
Thigh Maximum	.6269 (a)	.8442 *	.8117 *	.6768 (a)	.6776 (a)	.6212 (a)
Thigh Mean	.1471	.0304	-.0857	-.1429	-.3947	.0294
Thigh Standard Deviation	.6473 (a)	.4554	.8857 **	.3143	.6983 (a)	.3237
Thigh Ratio Maximum	-.6473 (a)	-.3947	-.8857 **	-.0857	-.6983 (a)	-.0883
Thigh Ratio Minimum	-.3284	-.2732	-.5218	-.3714	-.6160	-.1471
Thigh Proportion	.1791	-.2464	-.0290	-3189	-.0308	-.5075
Back						
Back Maximum	-.6172	-.1819	-.5508	-.2319	-.5768	-.2794
Back Mean	-.0617	-.4781	-.2609	-.4857	-.2125	-.5218
Back Standard Deviation	-.3086	.2390	-.1739	.0286	-.5768	.0580
Back Ratio Maximum	-.2469	-.7171	-.0290	-.6000	.5768	-.5798
Back Ratio Minimum	.1566	.4244	-.0735	.3189	.4620	.4265

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Table 74. Correlation coefficients (Spearman's rank) and their significance for discomfort and pressure variables with a limited and fully adjustable driving package (females).

Pressure Variable	**Correlation Coefficients (n=6)**					
	Mean Minutes		**Mean Rank**		**135 Minutes**	
	Limited	**Fully Adjustable**	**Limited**	**Fully Adjustable**	**Limited**	**Fully Adjustable**
Right Ischial Tuberosity (IT)						
IT Maximum	.0000	.8508 *	.3237	.6471 (a)	.2777	.8575 *
IT Mean	.0000	.4414	.3237	.0870	.2777	.5409
IT Standard Deviation	.4781	.8533 *	.7356 *	.6957 (a)	.3086	.6761 (a)
IT Ratio Maximum	-.4781	-.4030	-.7356	-.5882	-.3086	-.2572
IT Ratio Minimum	-.2425	.1941	-.5523	.0588	-.7045 (a)	.3087
IT Proportion	.3032	.6473 (a)	.5224	.2319	.5793	.3719
Right Thigh						
Thigh Maximum	.0926	.4630	-.0290	.8933 **	-.1765	.8061 *
Thigh Mean	.1852	.8452 *	.1160	.3947	.0000	.6473 (a)
Thigh Standard Deviation	.0000	-.5071	-.0580	.3947	-.0883	.0294
Thigh Ratio Maximum	-.2469	.8452 *	-.4058	.2125	-.5296	.5002
Thigh Ratio Minimum	.1879	.0514	-.0294	.0924	.0448	.0597
Thigh Proportion	..3395	.3651	.2609	-.0328	.0883	.2701
Back						
Back Maximum	.1518	-.6375 (a)	.1739	-.1765	.1543	-.3947
Back Mean	-.1518	.0304	-.2029	.2648	.4629	-.0911
Back Standard Deviation	.1518	-.6375 (a)	.2609	-.1765	.0000	-.3947
Back Ratio Maximum	-.4554	.7504 *	-.5798	.4545	.7715 *	.1876
Back Ratio Minimum	-.4554	.3947	-.6377 (a)	.1765	.8024 *	.5161

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Once again mean pressure values (for example maximum, mean and proportion) for the IT area, thigh area and low back, under both driving conditions were compared between those who reported discomfort (total minutes, mean rank, rating after 135 minutes) with those who did not. Mann-Whitney tests were conducted for males and females separately and together as a group. In contrast with Experiment 2 there were significant differences in IT pressure variables between males who reported discomfort and those that did not. Higher pressure values (maximum, mean, cell total and proportion) were found with the group of males who reported discomfort under the IT area, with the limited driving package (Table 75). There were also differences approaching significance with thigh maximum for males with the fully adjustable driving package, such that higher pressures were associated with males who reported more discomfort, for example 44.7 mmHg, SD 2.1 compared with 39.7 mmHg, SD 2.9 when divided into groups by the rating of 'discomfort after 135 minutes'. Considering females, there were differences approaching significance in thigh pressure values (mean and cell total) between those that reported and those who did not report discomfort for the fully adjustable driving package. For example, 30.02 mmHg (SD 3.4) compared with 20.5 mmHg (SD 2.7) when the sample was divided by subjects who reported and did not report discomfort after 135 minutes. There were no differences in low back pressures between the two groups of subjects.

Table 75. Ischial Tuberosity pressure values (mmHg) and significant differences between males who reported discomfort and those who did not with the limited driving package (n=6).

Right IT	Mean	Maximum	Sum of cells	Prop. of seat area	Significance
Mean Minutes					
Discomfort(n=3)	93.7 (11.9)	170.7 (47.1)	843.7 (106.5)	.42 (.03)	*
No Discomfort (n=3)	57.4 (3.2)	85.3 (15.6)	520 (28.2)	.25 (.06)	
Mean Rank					
Discomfort (n=6)	75.7 (21.2)	170.7 (47.1)	843.7 (106.5)	.42 (.03)	*
No Discomfort (n=0)	0	85.3 (15.6)	520 (28.2)	25 (.06)	
135 Minutes					
Discomfort (n=3)	93.7 (11.9)	170.7 (47.1)	843.7 (106.5)	.42 (.03)	*
No Discomfort (n=3)	57.4 (3.2)	85.3 (15.6)	520 (28.2)	25 (.06)	

N.B. (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

12.3.7 Interrelations Between Subjective Observations and Subjective Predictions of Hardness and Interface Pressure

As in Experiment 2, the Seat Detail data sheets (observed and predicted) from the questionnaire were used to obtain two groups of subjects for comparison . These groups were those who subjectively judged the seat 'too hard' and those who judged the seat 'just right' in the IT (letter K), thigh (letter M) and low back (letter G) areas. Males and females are considered together in order to increase the numbers for statistical analysis. Out of 68 Mann-Whitney tests there were only five significant results and two results approaching significance. These were as follows:-

1. A higher back maximum pressure (G) was associated with those who observed the seat to be too hard at the end of the trial with the fully adjustable driving package ($0.1>p>0.05$).
2. A higher maximum ratio in the thigh area (M) was found in subjects who observed and predicted the seat to be too hard with the fully adjustable driving package ($p<0.05$).
3. A higher maximum ratio in the low back area (G) was found in subjects who predicted the seat to be too hard with the limited driving package ($p<0.05$).
4. A greater proportion of the seat pressure was taken by the IT area (K) in subjects who observed the seat to be too hard with the limited driving package ($0.1>p>0.05$).
5. A higher minimum ratio was found in subjects who predicted the seat to be just right in the thigh area (M) with the limited driving package ($p<0.05$).
6. A higher maximum ratio was found in subjects who observed the seat to be just right in the thigh area (M) with the limited driving package ($p<0.05$).

12.3.8 Interrelations Between Subjective Observations and Subjective Predictions of Hardness and Discomfort

Subjects were again divided for comparison as above but this time comfort variables were compared (mean minutes, mean rank and rating after 135 minutes). Males and females were once again grouped together in order to increase the numbers for statistical analysis. The only consistent result was that subjects who subjectively predicted the seat to be too hard reported more discomfort in the IT area (letter K) but only with the fully adjustable driving package (Table 76).

Table 76. The reported IT discomfort of subjects who predicted the seat to be too hard or just right in the IT area with the fully adjustable driving package.

	Seat prediction-Too hard Mean (SD), Range, (n=4).	**Seat prediction-Just right** Mean (SD), Range, (n=7).	**Significance**
Mean minutes discomfort	90 (54.7), 30-150	12.86 (23.6), 0-60	**
Mean discomfort rank	4.05 (1.03), 2.6-5	2.9 (1.27), 1-4.2	(a)
Discomfort rating - 135 minutes	4.75 (0.5), 4-5	3.28 (1.49), 1-5	(a)

N.B. (a)=$0.1>p>0.05$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

12.3.9 Multiple Regression Analysis

As with Experiment 2, it was felt that multiple regression analysis would further aid the interpretation of the data. Despite the limitations of a small sample size (n=6), it was necessary that males and females were considered separately to obtain two approximately normally distributed samples. Attempts to combine the data (n=12) would result in a distribution with two peaks. Once again the technique was initially used to investigate the important variables in predicting interface pressure (IT, thigh and low back). The experimental condition of 'limited driving package' was used, as males in particular reported definite discomfort. As in Experiment 2, the mean pressure values taken from the IT, thigh and low back were thought to be the least prone to error for use. The data were not modified in any way to simplify interpretation of the results.

Considering mean IT pressure first as the dependent variable with the data set of males, regression diagnostics were used as previous, to identify possible outliers or points of influence. None were found. A multiple correlation table was then produced with mean IT pressure (the dependent variable) and age, body build (RPI), anthropometric data, postural angles and IT discomfort (the independent variables). A statistical method based on adjusted r-squared avoiding variables which showed strong multicollinearity (Variance Inflation Factor> 4), was used to decide the 'best fit' to the model. The best model involved the variables 'IT discomfort rating after 135 minutes', 'sitting height' and 'hip breadth' and accounted for 99.13% of the variance (Table 77). The variable 'neck inclination' improved the model slightly explaining 99.43% of the variance but the effect was insignificant and therefore it was not included in the equation. Although the sample size was small, the data met the assumptions for multiple regression analysis, allowing some confidence in the values of the regression coefficients.

Table 77. Variables entered into the multiple regression equation for 'best fit' of the model to the sample of males using the limited driving package. The dependent variable was mean IT pressure.

Variable	Adjusted r-squared	Significant change in F	Regression Coefficient (B)	Standard Error of B	VIF	Intercept
IT discomfort (135 minutes)	.8059	.0096	7.3046	1.0052	2.945	
Sitting height	.9332	.0606	.2025	.2811	1.224	
Hip breadth	.9913	.0442	-.4328	.0942	3.006	-16.4346

The same procedure of analysis was repeated for females using the limited driving package, however only the variable 'sitting height' produced a significant effect on adjusted r-squared explaining 64.95% of the variance. It was also not possible to create models with the male data using the fully adjustable driving package, the female data using the fully adjustable driving package and any of the data for the thigh and low back.

The variable 'IT discomfort rating after 135 minutes' was one of the important variables selected for predicting mean IT pressure for males using the limited driving package. It was therefore decided to attempt to attempt to build a regression model using the same procedure but with this as the dependent variable. However, only the variable 'mean IT pressure' produced a significant increase in adjusted r-squared accounting for 80.59 % of the variance. The variable 'neck inclination' improved the model slightly explaining 82.08% of the variance, but the effect was insignificant.

12.4 Discussion

Posture

With the limited driving package the male subjects were forced to adopt a more flexed posture than their optimum, but interestingly these angles were still within the recommended angles for comfort (Rebiffe, 1969), with the exception of neck inclination which was more flexed than recommended. This is perhaps not surprising as the posture 'forced' by the limited driving package was still realistic, being based on a well known small family car. The postures chosen by these males with the fully adjustable package were more 'open', but still within the recommendations for comfort. For example, increased arm flexion (mean 30 degrees, SD 12.6 compared with mean 20.3 degrees, SD 8.4, $p<0.01$), increased elbow angle (mean 103.3 degrees, SD 14.1 compared with 90.5 degrees, SD 17.7, $p<0.05$) and trunk-thigh angle (mean 102.1

degrees, SD 6.4 compared with mean 94.7 degrees, SD 12.4, 0.1>p>0.05). These males would clearly prefer a larger driving workspace, allowing the ability to more easily vary posture and so reduce discomfort as suggested by Akerblom (1948) in Keegan (1953), Kramer (1973) and Rebiffe (1980).

There were no significant differences in the postures selected by females between the two packages with the exception of elbow angle, in other words the limited driving package accommodated them quite well. A reason for this could be that the dimensions for the limited driving package were based on an Italian car. With this group of females arm flexion decreased with the fully adjustable package (32.5 degrees, SD 15 compared with 35.2 degrees, SD 17.1). Therefore the significantly increased elbow angle (121.5, SD 23.7 compared with 98.5, SD 22.2, p<0.01) was probably due to the ability to lower the steering wheel. The findings support a need for adjustability in the steering wheel enabling it to be brought lower and closer in relation to the body.

Positions of the controls

One of the main findings from this comparison of the two driving packages was the highly significant difference in steering wheel position. Both males and females preferred more adjustability in the steering wheel than that available in the small family car (used to define the limited driving package), desiring the ability to move the steering wheel further away from the body. For males, the mean preferred steering wheel distance from the body (L53-L11) was 372 mm (SD 23.3) with the fully adjustable package compared with 271 mm (SD 9.8), p<0.001 with the limited package. The same figures for females were 264 mm (SD 35.8) compared with 204 mm (SD 4.3). Females also preferred to have the steering wheel lower (p<0.01) in relation to their body in order to obtain their optimum posture.

Discomfort

Only the sample of males, reported more discomfort over time with the limited driving package, with many differences between the two packages approaching significance. The reason for this was that the males were forced into a more flexed posture with the limited package, whereas the females were not so affected by the increased space available with the fully adjustable package. Interestingly, 50% or more males reported neck, upper back and right shoulder discomfort after only 15 minutes with the limited driving package which varied little over time. Also, reported discomfort in the left shoulder, right shoulder, left arm and right arm also remained fairly static over time. These males were uncomfortable from the start with the constrained postures forced by the limited driving package and perhaps by the seat design itself. For example, 50-60% reported that both the seat cushion and backrest needed to be longer, compared with only one female who thought that the seat should be longer.

Both the group of tall males and short females reported low back discomfort with both driving packages (> 80% after 135 minutes with the limited driving package), suggesting that they were not comfortable with the seat design itself. This subject group represented the extremes in anthropometric dimensions and therefore are not normally considered by many car seat designers. Unsurprisingly it seems from the Seat Feature Checklist that the fixed lumbar support height was not optimum for either the tall males or short females. Both groups contained subjects who would have preferred it to be higher and lower than exists, perhaps resulting in the high frequency of reported low back discomfort early on in the trials. This finding supports the need for a lumbar support which is adjustable in height as also advocated by Porter and Norris (1987).

The mean number of minutes of reported discomfort was also higher for males in 17 out of 20 body areas, but for females only in 5 out of 20 body areas. Once again this type of graph shows clearly any differences between the two packages and the fact that males were clearly more uncomfortable than females. Statistical analysis of this data was not possible due to the small sample sizes.

Interface pressure

Both males and females had significantly higher pressures ($p<0.05$) in the IT area with the limited package. For example, a mean of 75.7 mmHg (SD 21.2) compared with 53.7 (SD 7.2) in males and a mean of 43.9 mm Hg (SD 7.3) compared with 41.3 mmHg (SD 6.5) in females. Pressures in the low back area were higher with the fully adjustable driving package despite both conditions having the same car seat. The differences were approaching significance for females (mean 25.9 mmHg, SD 7.3 compared with mean 21.1 mmHg, SD 7.3). It could have been that the females were able to adjust their posture to gain more support from the backrest with the fully adjustable package, but reported low back discomfort was still high for both driving packages. Pressures were very similar in the thigh area for both driving packages.

Consistent with Experiment 2 and the literature (Yang et al, 1984 and Zacharkow, 1988) there were significant differences between the sexes under the IT area for both driving packages, higher pressures being associated with males. In this experiment significant gender differences were also found in the thigh area, for example mean thigh pressure was 30.9 mmHg (SD 1.4) for males compared with 23.97 mmHg (SD

5.5) for females using the fully adjustable driving package ($p<0.05$). Also, as in Experiment 2, IT pressure variables were found to show strong, positive correlations with body build (RPI), such that thinner subjects had higher IT pressures whereas weight was a more reliable correlate with thigh pressure values, with heavier subjects having higher pressures. Although theoretically this finding was not unexpected, the only similar finding in the literature was the study by Garber and Krouskop (1982) of 70 spinal injured patients. Other authors may have viewed body build (RPI), weight etc., as perhaps too crude for analysis.

Agreeing with the findings of Experiment 2, the relationship between posture and interface pressure was still unclear, despite the more flexed posture for males with the limited driving package. The lack of correlations could be explained by the fact that with two fairly small homogenous groups there was not the continuum of postures or body types. As discussed in Experiment 2, it was only in studies where posture was more systematically controlled (Linden et al, 1965; Bush, 1969 and Shen and Galer, 1993) that a clear relationship between posture and interface pressure was shown.

Investigations of correlations between pressure and discomfort variables revealed more significant trends especially with the group of tall males. Although the car workstation dimensions were taken from a well known small family car, uncomfortable postures (although within recommended ranges) were forced with this group. For these males IT pressure variables were significantly, positively correlated with reported IT discomfort for both packages, for example a correlation coefficient of 0.8332 ($p<0.05$) between mean IT pressure and mean discomfort rank. Thigh pressure variables in males also significantly positively correlated with reported thigh discomfort for the limited package. For the group of short females there were only correlations approaching significance between thigh pressure values and reported discomfort and only with the fully adjustable driving package. Reported discomfort in females was very similar for both driving packages perhaps explaining the lack of significant correlations.

It appears that higher pressures were found in subjects who reported discomfort. In males using the limited driving package there were significant differences in IT pressure values between those who reported IT discomfort compared with those who did not, higher pressures being associated with more discomfort. For example, using the limited driving package there was a mean IT pressure of 93.7 mmHg (SD 11.9) for males that reported discomfort after 135 minutes, compared with 57.4 mmHg (SD 3.2) for males who reported no discomfort. Males who reported thigh discomfort after 135 minutes also had a higher thigh maximum with the fully adjustable driving package i.e.

44.7 mm Hg (SD 2.2) compared with 39.7 mm Hg (SD 2.9), 0.1>p>0.05. The results were again more inconsistent for females, with a difference only approaching significance between females reporting discomfort and those not, using the fully adjustable driving package, the thigh pressures being higher with those who experienced thigh discomfort. This result could easily have occurred by chance. There were no differences in low back pressure between those that reported low back discomfort and those that did not for both males and females.

The data were explored extensively to find out if those subjects who observed or predicted seat hardness had different pressure values, but the results were still unclear, with isolated significant results in different body areas. The data were then used to find out if subjects who observed or predicted that the seat was too hard reported more discomfort. It was found that subjects who predicted that the seat would be too hard reported more discomfort in the IT area, but for the fully adjustable driving package only. The reason why this was not the case with the more restricted package cannot be explained, leading once again to the conclusion that the results of this analysis were unclear.

Multiple regression analysis revealed the variables of 'IT discomfort rating after 135 minutes', 'sitting height' and 'hip breadth' as being the most important for the prediction of 'mean IT pressure', but only for the sample of tall males using the limited driving package. These variables explained 99.13% of the significant variance in the data and therefore were highly likely to be good predictors of mean IT pressure with this sample. The data also met the assumptions for the multiple regression model as far as possible, considering the small sample size. These males were in more flexed postures than their optimum, exhibited a large range of IT pressure values (mean 75.7, SD 21.2) and 67% experienced buttock discomfort. Although unusual, this driving situation is possible in the real world setting.

12.5 Conclusions

1. Discomfort was more frequently reported by males using the limited driving package. These males were able to take advantage of the additional space available with the fully adjustable package resulting in a reduction in their reported discomfort. These differences i.e. posture and discomfort changes, were not apparent in females.

2. The more flexed posture for males with the limited driving package (although generally within recommended comfort angles) was associated with more reported discomfort in the buttocks and significantly higher pressure values in the IT area. Females also had significantly higher pressures in the IT area with the limited driving package but differences in reported discomfort were not significant.

3. As with Experiment 2 the pressure values for males were significantly higher than those for females in the IT and thigh areas, implying that it is necessary to consider gender when evaluating any absolute values of pressure. Similar pressure values were found in the low back.

4. Consistent with Experiment 2, thinner subjects (high Reciprocal Ponder Index) had significantly higher IT pressures and heavier subjects (weight) had significantly higher thigh pressures. Consequently it is also necessary to consider body build in the interpretation of any pressure data.

5. Once again, no consistent relationship was found between interface pressure variables and posture.

6. Significant trends were found with the group of tall males, in particular higher IT pressures were associated with more reported discomfort for both driving packages.

7. Comparing males who reported buttock discomfort with those who did not using the limited driving package, significantly higher pressure values were found with the former group.

8. Once again, the subjects predictions (and observations) of seat hardness were not consistent with areas of higher pressures or more reported discomfort, even with the limited driving package.

9. The results of the multiple regression analysis with the data set from the sample of tall males using the limited driving package, revealed the variables of 'IT discomfort rating after 135 minutes', 'sitting height' and 'hip breadth' as being important for the prediction of mean IT pressure and explained 99% of the variance.

10. The fact that most of the significant findings regarding interface pressure and discomfort were only with this homogenous sample of tall male subjects, using the limited driving package (not the fully adjustable package), leads to uncertainty regarding the use of this data as a predictive tool for discomfort.

The final discussion and conclusions regarding the results of this experiment together with Experiments 1 and 2 are presented in Chapter 13.

Chapter 13 General Discussion and Conclusions Regarding Experiments 1, 2 and 3.

13.1 Introduction

This chapter reports the main findings from Experiments 1, 2 and 3 which are presented in detail in Chapters 10, 11 and 12. These findings are discussed in the light of the literature, with their limitations or weaknesses and their consequent importance for practical application in the automotive industry. Suggestions for future work are given in Chapter 14.

13.2 Discussion of the Main Findings of Experiments 1, 2 and 3.

Posture and the position of the controls

As a result of Experiment 1 new guidelines for postural comfort were proposed (Table 78). In general, subjects (males and females together) preferred to sit slightly more upright (smaller trunk-thigh angle) than the theoretical recommendations of Rebiffe (1969) and Grandjean (1980), with their arms more extended (greater arm flexion and elbow angle). Knee angle and foot-calf angle were very similar to the above authors' recommendations. In this sample it was also found that males preferred a more reclined posture and females a more flexed, upright posture with significant differences in arm flexion, elbow angle and trunk-thigh angle. This was found to be a body size difference rather than a sex difference. Limitations in the flexibility of the hamstrings could be an important factor in influencing the adoption of a more reclined posture in taller subjects as trunk-thigh angle positively correlated with knee angle ($p<0.001$).

These new postural recommendations were compared with the posture data from the fully adjustable driving package in Experiment 3, with the tall male and short female subjects. Similar ranges were found for trunk-thigh and elbow angles but the 'lower end' of the ranges for arm flexion (7 degrees) and neck inclination (7 degrees) were less, leading to a modification of the final guidelines. The upper levels were within those proposed by Experiment 1 but still outside those of Rebiffe (1969) and Grandjean (1980). Table 78 summarises the development of the new guidelines for postural comfort.

Table 78. Summary of postural angles for comfort (degrees).

	Rebiffe (1969)	**Grandjean** (1980)	**Experiment 1** 95% confidence limits	**Experiment 3** Fully adjustable package - observed posture	**New Guidelines**
Neck inclination	20-30	20-25	29-63	7-51	5-60
Trunk-thigh angle	95-120	100-120	89-112	94-112	90-110
Knee angle	95-135	110-130	103-136	104-133	105-135
Arm flexion	10-45	20-40	16-74	7-54	5-75
Elbow angle	80-120	-	80-161	88-150	80-160
Foot-calf angle	90-110	90-110	81-105	85-105	80-105
Wrist angle	170-190	-	-	-	

N.B. The new guidelines have been given to the nearest multiple of 5 degrees.

The tall males in Experiment 3, using the limited driving package, were forced to adopt a more flexed posture than their optimum and were consequently more uncomfortable. However, the fact that these angles (with the exception of neck inclination) were still within the recommended angles for comfort (Rebiffe, 1969) and also the new guidelines outlined above, must bring into question whether the use of simple recommended postures for comfort are relevant. It seems that posture should always be considered in the context of the whole driving situation / workstation and that these recommended angles for comfort should only ever be used as guidelines by ergonomists and designers. It is also always important to remember that these results give a range of postures to suit a range of people, but not all people will be happy with the whole range as individuals.

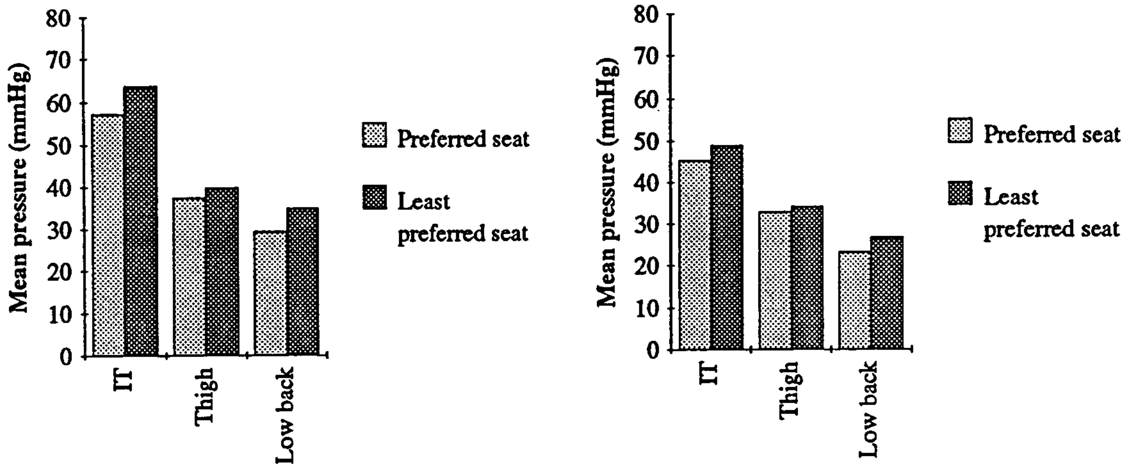
The results of these experiments support the fact that drivers, especially those at the larger end of the extremes of anthropometric dimensions, have to compromise their preferred driving posture in order to fit many cars on the market today. The data also support a strong need for both horizontal and vertical adjustment in the steering wheel in order for individuals to obtain their optimum postures, particularly with respect to arm flexion and elbow angle. Thus, there is an urgent need for major car manufacturers to become more proactive in their consideration of the people who purchase their vehicles.

Discomfort and pressure

It seems from the results of Experiments 2 and 3 that the simple quantification of interface pressure data from a variety of individuals, with the assumption that high (or low) pressure values are predictors of increased discomfort is unsatisfactory. The results of the two experiments illustrate this lack of clarity.

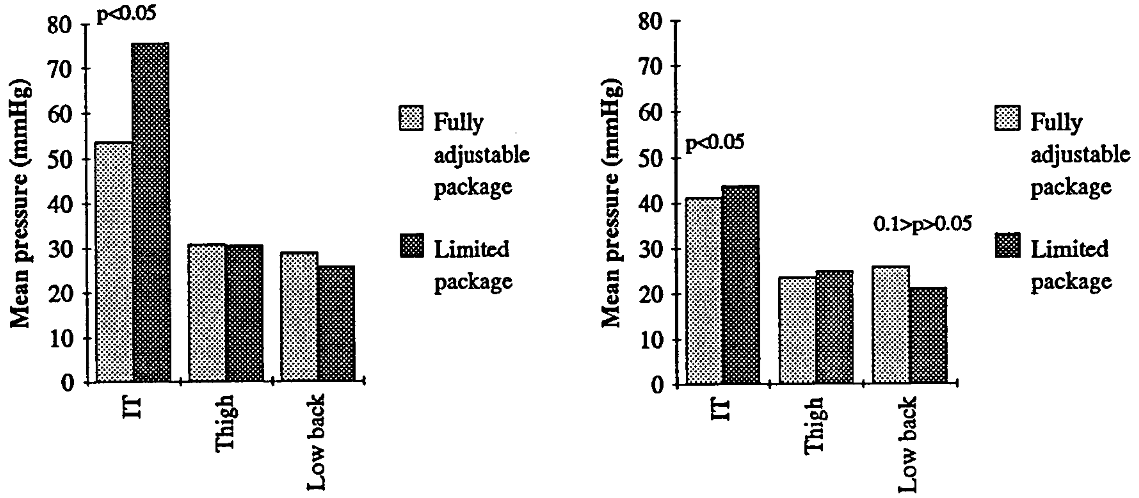
In Experiment 2, subjects sat in their optimum posture and it was expected that the larger driving space created by this posture would give greater freedom of movement, important in the avoidance of discomfort (Akerblom, 1948 in Keegan 1953; Kramer, 1973 and Rebiffe 1980), but that the least preferred (usually harder) seat would cause more discomfort over time. This was generally the case for males with a trend for more discomfort at each time period (Figure 37, Chapter 11.4.3) and significant differences ($p<0.05$) between the two seats for the total minutes of reported discomfort in the right buttock and left and right thigh. There was little difference in reported discomfort over each time period for the females between the two seats (Figure 38, Chapter 11.4.3) and no significant differences in the total number of minutes of reported discomfort, despite obvious differences in foam hardness. Figure 44 represents graphically the mean IT, thigh and low back pressures as an example of some of the descriptive data for seat pressure. The mean pressure values were selected as being the most stable and least prone to measurement error. Referring to Figure 44, graphs a) and b), it can be seen that no significant differences were found in mean IT, thigh and low back area pressures between the two conditions for either sex, once again despite differences in foam hardness. Although there was a trend for higher pressures with the least preferred (often harder) seat, the ranges of differences were small, 1-4 mmHg (females) and 2-7 mmHg (males). As the sample of males experienced significantly more minutes discomfort with their least preferred seat in the IT area, it could at this stage be tentatively hypothesised (taken from Figure 44 a) that a mean pressure of 64 mmHg or greater in the IT area in males would lead to discomfort during a 2.5 hour drive. However, against this theory, correlations between IT discomfort and pressure data for males (Table 60, Chapter 11.4.7) were not consistent. Also, scrutiny of the data revealed that three out of the seven males had mean IT pressures higher than 64 mmHg with their least preferred seat, but two of these males had no IT discomfort over the whole experimental driving period.

Figure 44. Mean pressure values for both experimental conditions for males and females.



a) Males (n=7)

b) Females (n=7)



c) Males (n=6)

d) Females (n=6)

The only consistent, significant, relationship between comfort and pressure variables in Experiment 2 was found for females only, with their preferred seat. In this case significant negative correlations were found between low back pressure and discomfort variables, i.e. reports of discomfort were less as pressure increased. Reported discomfort over time was the same for both seats, but there was a trend (not significant) for more total minutes discomfort with their preferred seat. It could be that the mean pressure for the preferred seat of 23 mmHg (range 19-29) was too low for adequate support, although this mean value was only 3 mm Hg lower than the mean for the least preferred seat.

Moving on to Experiment 3, on this occasion the seat was held constant and posture was varied within realistic constraints by comparing a limited driving package (based on a well known small family car) with a fully adjustable package. In an attempt to ensure that there was some reported discomfort and a large range of pressure values, subjects were selected who represented the extremes of anthropometric dimensions, i.e. the very tall and the very short, being close to or outside the normal range of design criteria. Generally, there was more reported discomfort than Experiment 2 especially with the sample of tall males. As with Experiment 2, there was little difference in the frequency of reported discomfort in females between the two driving packages (Figure 42, Chapter 12.3.2). The tall males however, were forced into a more constrained posture by the limited driving package and consequently reported more discomfort over time and in more body areas (Figure 41, Chapter 12.3.2). Referring once again to Figure 44, graphs c) and d), it can be seen that there was a large and significant difference ($p<0.05$) in the mean IT pressure for males between the two driving packages (75.7 mmHg with the limited package, compared with 53.7 mmHg for the fully adjustable package). Consistent, significant correlations were found for the sample of males between the IT discomfort and pressure variables for both driving packages, but less so for females. Also, the variable 'IT discomfort after 135 minutes' was selected along with 'sitting height' and 'hip breadth' as a significant predictor of mean IT pressure explaining 99% of the variance, but only for these tall males using the limited driving package. For these males it could be hypothesised that IT pressures of 75 mmHg or greater (taken from Figure 44, graph c) would lead to discomfort. This was supported by the fact that the three males with IT pressures greater than 75 mmHg reported some discomfort over the whole driving period with the limited driving package, whereas the other three males reported no discomfort. However, considering these same males using the fully adjustable driving package, no individual had a mean IT pressure above 75 mmHg, although 50% of them reported some discomfort. Clearly, setting absolute values for IT pressures to predict discomfort is not satisfactory even for this homogenous group of males.

The significantly higher pressures for females with the limited driving package ($p<0.05$), were not reflected in significantly higher reported buttock discomfort, unlike the sample of males. It seems that males were sensitive to the effects of the increased IT pressure caused by a harder seat (Experiment 2) and a constrained posture (Experiment 3). Similar pressures were found under the thighs between the two packages for both males and females, although there was more variation between the two packages in the values for males with the limited package. Consequently, significant correlations were found between thigh pressure values and thigh discomfort for males only with the limited package.

The frequencies of reported discomfort in the low back for both males and females were high (> 80% after 135 minutes with the limited driving package), but no consistent correlations between the back discomfort variables and low back pressure values were found. There was a difference approaching significance for mean low back pressure for females, with higher pressures for the fully adjustable driving package (25.9 mmHg compared with 21.1 mmHg), despite similar high levels of low back discomfort reported with both packages. This result could be due to greater variability in the low back pressure data or could have occurred by chance.

The lack of a simple relationship between pressure values and discomfort can also be illustrated by the low back data from the two experiments. In Experiment 2, the mean low back pressure for males with their preferred seat was 29 mmHg and there was little reported low back discomfort i.e. only one male reported some discomfort after 135 minutes. However despite a mean low back pressure of 29 mmHg in males with the fully adjustable driving package in Experiment 3, 33% of them reported discomfort in the low back after 15 minutes rising to 67% after 135 minutes. These subjects in Experiment 3, representing the extremes in anthropometric dimensions and so not normally considered by designers, had problems with the back rest of this seat, with 33% of males and 33% of females having discomfort in the low back after 15 minutes with both driving packages. This is confirmed by data from the Seat Feature Checklist, which showed that both the sample of males and the sample of females contained subjects who would have preferred the lumbar support to be higher or lower than it was. This finding supports the need for a lumbar support which is adjustable in height as advocated by Porter and Norris (1987).

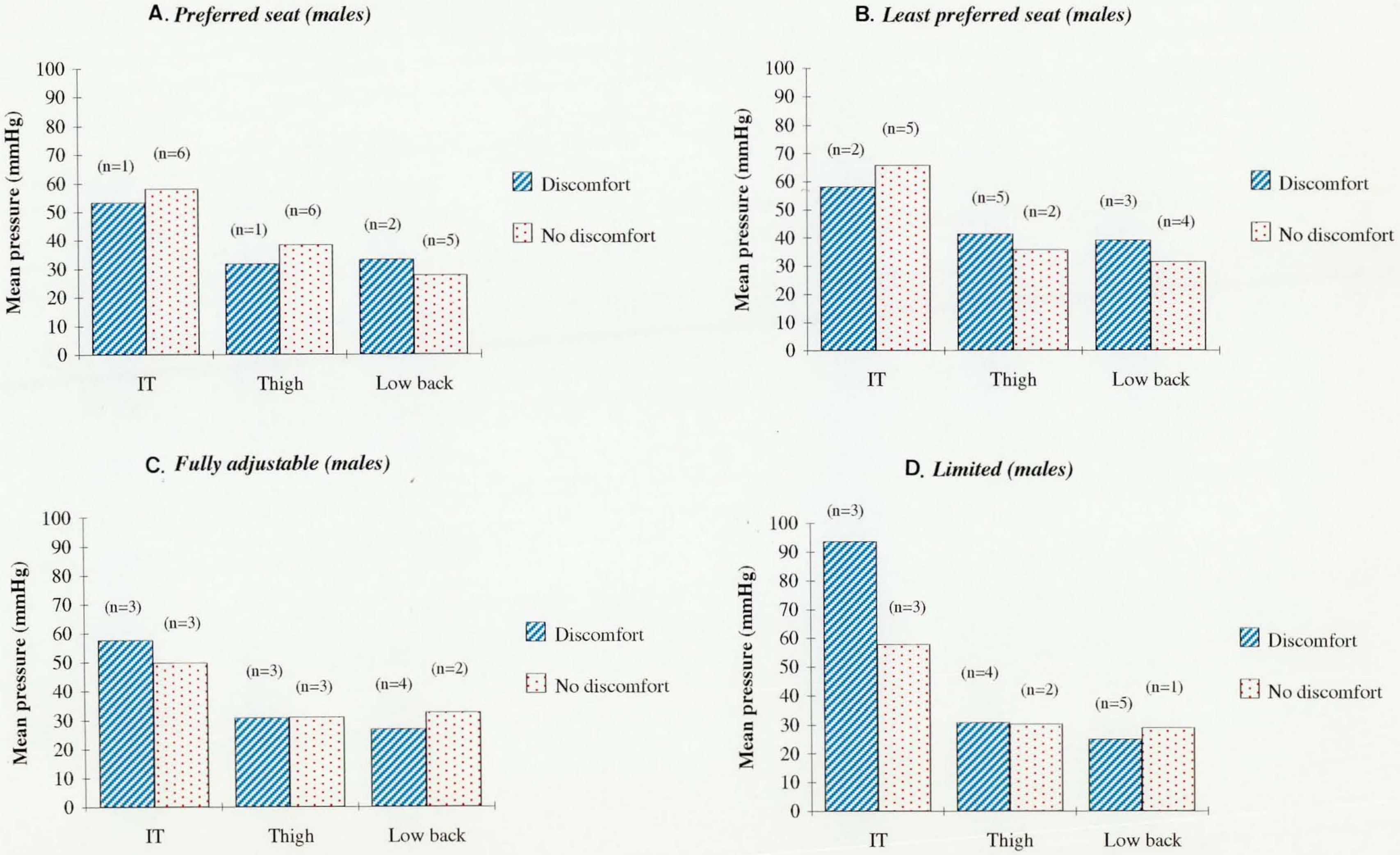


Figure 45. Mean pressure values according to reported discomfort (males).

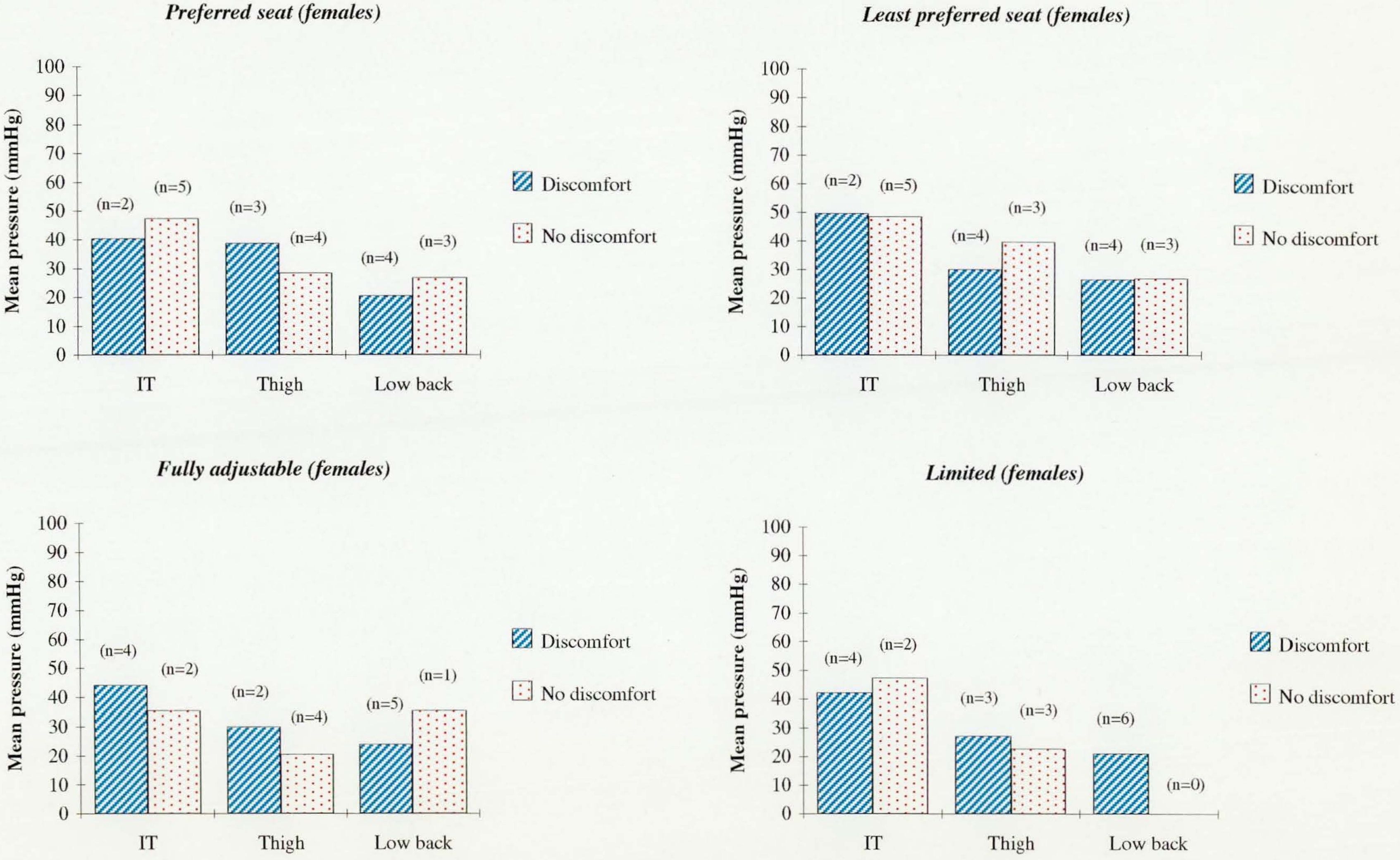


Figure 46. Mean pressure values according to reported discomfort (females).

Figures 45 and 46 illustrate the difficulties of selecting a range of interface pressure values for predicting driver discomfort, even if males and females were considered separately. For example, with males (Figure 45), higher mean IT pressures were associated with reported discomfort in graphs a) and b) whereas lower mean IT pressures were associated with reported discomfort in graphs c) and d). Similar inconsistencies can be seen with the thigh and low back data, and also the data for the females. These graphs again illustrate that the technique is not robust enough to be used as a predictive tool for discomfort in the automotive industry.

Differences in discomfort between the preferred and least preferred seat, despite obvious differences in foam hardness, were not as great as the differences in discomfort between the two driving packages in Experiment 3. In the former case subjects were sat in their optimum posture for both seats and this shows the importance of a good posture in the avoidance of discomfort. It could be that these results support the idea that a good posture is more important than a good seat in reducing driver discomfort. Also, females in Experiment 2 reported similar discomfort between the two experimental conditions sat in their preferred posture despite obvious differences in foam hardness. Rebiffe (1969) also believed that discomfort was caused by the poor dimensional arrangement of the driving workstation rather than the seat itself.

Direct comparison of the pressure values obtained in these experiments with those in the literature is difficult because of the different experimental conditions or lack of information on these conditions, for example body type, seat surface, task carried out and pressure measurement technologies. Kurz et al (1989) actually makes recommendations for ergonomic vehicle seat design, for pressures directly under IT to be 75-225 mmHg and immediately around the IT to be 60-113 mmHg. Unfortunately, it is not known if these are maximum or mean values and no method or reference is given, but they are clearly higher than the values found in Experiments 1 and 2. Sember III (1994) advises that the maximum pressure that can be sustained under the IT's without discomfort after 15 minutes was 62 mmHg for men under 30 and women under 40. However, he goes on to advise that constant pressures as low as 26 mmHg for the over 40's and 15 mmHg for the elderly, will lead to discomfort. Age was not found to be related to increased discomfort or higher pressures values in either Experiment 2 or 3, but separate analyses of the over 40's and the elderly were not carried out. Kamijo et al (1982) recommended mean pressures of 11.25-18 mmHg for supporting the lumbar area in car seats, although only one male subject was used in their experiments. This is lower than any of the mean pressures in the low back for both Experiments 2 and 3. For example, once again referring to Figure 44, the range mean low back pressures for graphs a), b), c) and d) was 21- 35 mmHg.

As already discussed in Chapter 8.4.5, despite the automotive industries' interest in interface pressure measurement, critical appraisal of the literature does not support the finding of a simple relationship between discomfort and pressure. Many of these studies were unclear about their results in terms of the specifics of the experimental design and data analysis. They were also often based on short term discomfort evaluations or had a small number of subjects. Many concluded that further study was required.

Finally, for both experiments the subjects' predictions (and observations) of seat hardness were not consistent with areas of higher pressures or more reported discomfort. It seems that the subjects judgements of seat hardness in the IT, thigh and low back areas, either at the beginning of the trial (showroom style) or after 135 minutes, did not relate to the body areas which discomfort was experienced. It may be that 'trained subjects' are required to make these 'expert judgements'. Perhaps subjective judgements of 'seat pressure' or 'areas of the seat causing discomfort' rather than ' seat hardness' may have revealed more significant outcomes. The use of different adjectives could be investigated in future work.

Other factors affecting interface pressure values

In agreement with Yang et al (1984), for both experiments males generally had higher pressures values than females, significantly so under the IT area (Experiment 2, both conditions) and the thigh area (Experiment 3, both packages). The variables of 'sex' and 'hip breadth' (which is probably sex related) were also selected by the multiple regression analysis as being the best predictors of mean IT pressure in Experiment 2. Reasons for these higher pressures in the males were suggested by Zacharkow (1988) as being males having less subcutaneous fat in the buttocks and hips, being more heavily built above the pelvis and the fact that the IT's and the acetabula (the sockets for the head of the femur) are closer together with the ischia being more inverted in shape. This could account for the higher sensitivity of males to the harder seat (Experiment 2) and the constrained posture (Experiment 3). Sember III (1994) hypothesised that sex differences in the distribution of subcutaneous fat become less over the age of 40 years. There were no significant correlations between age and discomfort or pressure in either experiment, but the over 40's were not investigated separately due to their low number.

Also consistent with the findings of Garber and Krouskop (1982), thinner subjects (high Reciprocal Ponder Index) had higher IT pressures, although Yang et al (1984) failed to find such a relationship in their study. The sample of males in Experiment 3, who had the highest IT pressures also were generally thinner than the other sample groups. For example, the mean Reciprocal Ponder Index (RPI) for these males was 47.4 (SD 5.5) compared with 41.5 (SD 1.3) for the short females, 42.4 (SD 1.6) for the more varied group of males in Experiment 2 and 39.9 (SD 2.2) for the females in Experiment 2. In both experiments significant positive correlations were also found between weight and thigh pressure values, although once again this is in disagreement with Yang et al (1984). It is proposed that the lack of significant findings in the study by Yang et al (1984) could be due to their small ranges of height (1450-1720 mm) and weight (42-79 kg) or maybe even differences in the body build of the Chinese subject group. Further research is needed to verify this. Finally, very few of the studies discussed in Chapter 8.4.5, including the recently reported ones such as Gross et al (1994) and Shen and Galer (1993), considered gender or differences in body build when reporting their findings.

Pressure distribution is influenced by posture under controlled experimental conditions. For example, Treaster and Marras (1987) found that using an experimental chair in different postures, both seat and backrest angles had an effect on seated pressure distribution; and Shen and Galer (1993) found that six changes in the angle of an experimental chair were reflected in the pressure values. However, the lack of a clear relationship between posture and interface pressure values in Experiments 2 and 3 indicates that this relationship is not robust for 'real world' applications.

13.2.1 Weaknesses / Limitations of the Experiments

The static driving rig

The validity of the recommendations regarding driving posture and the positions of the controls using only a static driving rig were discussed in Chapter 10.4. Briefly, the author is aware that subjects do adopt different postures due to the constraints imposed by different vehicles and that inevitably compromises are made in order to obtain the optimum driving posture. This confounding is difficult to control for when measuring a static or dynamic posture in different vehicles. As Rebiffe (1969) and Grandjean (1980) both based their analyses of a comfortable driving posture on the theoretical requirements of the driving task, the optimum postural angles for driving obtained from subjects using a standardised car seat on the driving rig should be an improvement. It is suggested that further work is needed to determine how much an individual's posture varies with different vehicles and dynamically in different driving situations.

Pressure measurement technology

There is no doubt that the exploratory work regarding the Talley Pressure Monitor Mark 3 (TPM) described in Chapter 9 helped considerably in obtaining the best quality data from the system. These exploratory experiments led to a better understanding of the strengths and weaknesses of the system. Also, the fact that these experiments were repeated by Giacomin (1995) at the Fiat Research Centre, with similar conclusions gave further confidence in the results. The decision to design a half-matrix covering the right hand side of the seat for pressure measurement, was justified by the need to get as high a resolution of the cells available as possible. It was also noted from earlier data and by other authors (Bush, 1969; Drummond et al, 1982; Congleton et al, 1982 and Eckrich and Patterson, 1991) that there was little asymmetry in seated pressure maps. Although the method of extraction of useful pressure data, the checking and the entry onto spread sheets was very time consuming, there was no alternative with no affordable and useful quantification software available. The technologies for measuring interface pressure are continuing to improve, although the costs of this equipment and software still far exceed those of the TPM. Many of the new technologies have a high resolution of cells on the matrix, fast scanning rates, more robust cells, utilise highly interactive software for editing and data analysis, allow the quantification of pressure over time (dynamic), and allow the real time viewing of the pressure data such that error due to a bent cell for example, can be eliminated. The time saved in the use of some these new systems would allow the measurement and analysis of the data from a greater number of subjects in the time available, which would have the obvious advantage of increasing confidence in the results.

Sample size

Larger sample sizes for the experiments, using the strata of gender, age and body build would have given more confidence in the findings and allowed more statistical analyses to be carried out. However, under the constraints of time and cost it was not possible to carry out further experimentation. The conclusions of these experiments therefore must be judged in the light of the small sample sizes and this being a preliminary study.

13.3 Conclusions

1. New guidelines for optimum postural comfort have been developed. However it is advised that posture is always considered in the context of the whole driving situation or workstation and that recommended angles for comfort are only ever used as guidelines by ergonomists and designers. These guidelines represent a range of optimum postures and any single individual should not be assumed to be able to adopt any posture in the range. Consideration of the interrelations between different postural angles, such as the effect of trunk-thigh angle on knee angle, is also important.

2. Car manufacturers must become more proactive in their consideration of the people who purchase their vehicles. The findings of these experiments show that many drivers, especially those at the larger end of the extremes of anthropometric dimensions, have to compromise their preferred driving posture in order to fit many of the cars on the market today. This has obvious consequences for the discomfort experienced. Both horizontal and vertical adjustment of the steering wheel would allow individuals to obtain their optimum postures, particularly arm flexion and elbow angle.

3. Posture could be more important than a good car seat in the avoidance of discomfort. Further investigation is needed to verify this.

4. The simple quantification of interface pressure data from a variety of individuals, with the assumption that high, or even low pressure values in the case of the low back, are predictors of increased discomfort is unsatisfactory. It seems that this technique is not robust enough to provide such information to the automotive industry in 'real world situations' i.e. a variety of subjects (male, female, body builds, ages) with different car seat designs.

5. Males were sensitive to the effects of the increased IT pressures caused by the harder seat (Experiment 2) and the constrained posture (Experiment 3). The higher pressures were due to the physiological facts that men have less subcutaneous fat in the buttocks and hips, they are heavier above the pelvis and that the IT's and the acetabula are closer together with the ischial tuberosities being more inverted in shape. The preferred postures adopted by the taller group of males will also affect the pressure values. For

example, if the leg was not supported under the thigh then higher pressure values would be found under the ischial tuberosities.

6. Body build appears to have a significant effect on pressure values in the IT and thigh areas, such that thinner subjects (high Reciprocal Ponder Index) had higher pressures in the IT area and heavier subjects (weight) had higher pressures under the thigh.

7. Perhaps as a result of points 5 and 6, there were consistent, significant relationships between IT pressure values and IT discomfort variables, but only for the sample of very tall males (95th percentile stature and above). These males would be outside the anthropometric dimensions considered by many designers working in the automotive industry. Due to the constrained postures imposed by many vehicles they could also be expected to experience discomfort more frequently than other car users. The fact that pressure values could only potentially be used as predictors of IT discomfort with this 'extreme' sample, invalidates interface pressure measurement as a robust predictive technique for discomfort, for use in the automotive industry.

8. Interface pressure measurement could be proposed as an aid to the process of seat design by monitoring under controlled conditions (i.e. sex, build, posture, seat surface), areas of high and low pressures on the car seat itself, using subjects from the driving population. For example, if feedback from several customers revealed that high pressures under the thigh were causing significant problems with discomfort for short women, experiments could be set up with different prototypes, (for example, with respect to foam hardness, fabric and shape) to investigate this.

Chapter 14 Suggestions for Future Work

14.1 Introduction

Conclusions regarding this work have been presented in the discussion chapters at the ends of Parts I and II. High exposure to driving has been linked to sickness absence and discomfort especially in the low back. Techniques were identified from the literature for further investigation which could potentially aid the automotive industry in the prediction of driver discomfort at an early stage in the design process and so prevent some of the musculoskeletal problems identified. Interface pressure measurement was investigated in detail, but was not found to be robust enough for such 'real world' application. Ideas for future areas of investigation regarding driver discomfort are now listed in this chapter.

14.2 Future Work

The following suggestions are made to follow on from the research carried out in Parts I and II:-

1. To carry out a prospective cohort or longitudinal study of subjects with exposure to driving at different levels i.e. newly employed drivers, low mileage drivers and high mileage drivers with no recent history of low back trouble. As well as questionnaire data, this should where possible be backed by more objective data for example medical records or medical examination, work records or observation of the task, motivation or job satisfaction indicators, details regarding the actual model of car used and any adjustment features. This would provide information regarding the incidence of low back / musculoskeletal troubles and aid understanding of the 'cause / effect' relationship allowing more confidence in the results.

2. To carry out a case control study where subjects with a high exposure to driving as part of their job are matched with subjects of the same sex and age who have a low exposure to driving. The data collected would be similar to Point 1, giving the benefit of increased confidence in the results.

3. To set up contacts with the managers, employers, fleet managers etc., of companies with a large number of individuals with high exposure to driving as part of their job, and explore the effects of training in the benefits of appropriate adjustment of posture, choosing suitable cars and rest breaks on discomfort in the low back and sickness absence with low back trouble. This would be similar to the recent raising of awareness regarding factors such as the dangers of lifting or sitting for long periods of time at VDU's. The effects of any such training must be fully evaluated.

4. Where possible involve the automotive industry in research aimed at the improvement of driver comfort. If they can be persuaded that they risk a fall in their market share if they do not provide affordable, safe and comfortable driving packages, the consumer will benefit.

5. To set up a study to measure the actual postures that subjects adopt in their own vehicles in different driving situations. Additionally, information regarding the reasons why subjects adopt certain postures, particularly if they are due to constraints in the driving workstation, would be useful.

6. The 'acid' test for the ability of interface pressure measurement to predict driver discomfort would be to compare dynamic discomfort data with interface pressure data (outlined in Experiment 4, page 145). This experiment was completed, although it has not been presented within this thesis. The preliminary analysis has failed to find a clear relationship between pressure values and subjective comfort. Further analysis would be desirable.

7. With the availability of better technologies for the measurement of interface pressure, the data could be explored more accurately, extensively and interactively. For example, in a paper by Thakurta et al (1995) the relative distribution of pressure over the whole seat was evaluated. The equipment which they used also allowed the measurement of pressure over time. However, despite this their preliminary results still concluded that the prediction of car seat comfort / discomfort was a complex problem.

8. To set up a series of experiments in the field to explore in more detail the effects of the postures adopted (due to the constraints enforced by the driving workstation layout) on reported discomfort over a medium term drive. Examples of such postures are those caused by poor alignment of the trunk with the pedals, a low car roof with tall individuals, a steering wheel being positioned too close to the body and high pedals with a small foot size.

9. To carry out a review of the literature in order to set up a series of studies to investigate the psychological factors which may influence reported driver discomfort such as mood, stress, aesthetics of the seat / driving workstation or individual perceptions of discomfort.

10. To investigate the use of other scales for the rating of local discomfort in the thighs, buttocks and low back. Cross correlations could then be carried out between these scales to test which ones were most reliable for the evaluation of discomfort in these body areas. Ideally this scale would produce a normal distribution of ratings and allow parametric statistical analyses to be carried out. An example of such a scale suitable for further investigation is that developed by Ellermeier et al (1991), described in Chapter 8.2.2.

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Appendix 1

The Musculoskeletal Disorders Questionnaire

Vehicle Ergonomics Group

Musculoskeletal Disorders Survey

Subject Number ☐☐☐☐

Location ______________________

____

Interviewer ______________________

Date ☐☐ ☐☐ ☐☐

Time ☐☐ ☐☐ am / pm

Personal Details

		Male	**Female**		
1	Sex	1☐	2☐		
		Day	**Month**	**Year**	**Age**
2	Date of Birth	☐☐	☐☐	☐☐	or ☐☐
		Stones	**Pounds**		**Kg**
3	What is your weight?	☐	☐		or ☐☐☐
		Feet	**Inches**		**cm**
4	What is your height?	☐	☐		or ☐☐☐
		Right	**Left**	**Able to use both hands equally**	
5	Are you right handed or left handed?	1☐	2☐	3☐	

N.B. Reduced size.

Musculoskeletal disorders

2

Please answer by using the tick boxes. ☑ **one tick for each question.**

Please note that this section of the questionnaire should be answered, even if you have never had trouble in any part of your body.

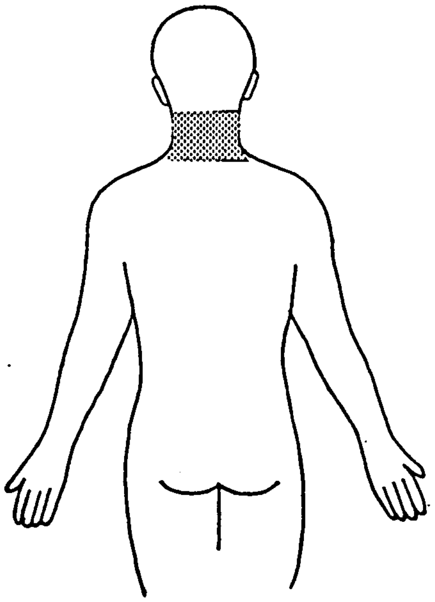
TO BE ANSWERED BY EVERYONE	ONLY TO BE ANSWERED BY THOSE WHO HAVE HAD TROUBLE	
Have you at any time during the **last 12 months** had **trouble (such as ache, pain, discomfort, numbness)** in :	Have you had trouble during the **last 7 days** :	During the **last 12 months** have you been **prevented** from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble :
1 *Neck* No Yes 1 ☐ 2 ☐	2 *Neck* No Yes 1 ☐ 2 ☐	3 *Neck* No Yes 1 ☐ 2 ☐
4 *Shoulders* No Yes 1 ☐ 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in both shoulders	5 *Shoulders* No Yes 1 ☐ 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in both shoulders	6 *Shoulders (both/either)* No Yes 1 ☐ 2 ☐
7 *Elbows* No Yes 1 ☐ 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in both elbows	8 *Elbows* No Yes 1 ☐ 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in both elbows	9 *Elbows (both/either)* No Yes 1 ☐ 2 ☐
10 *Wrists/hands* No Yes 1 ☐ 2 ☐ in the right wrist/hand 3 ☐ in the left wrist/hand 4 ☐ in both wrists/hands	11 *Wrists/hands* No Yes 1 ☐ 2 ☐ in the right wrist/hand 3 ☐ in the left wrist/hand 4 ☐ in both wrists/hands	12 *Wrists/hands (both/either)* No Yes 1 ☐ 2 ☐
13 *Upper back* No Yes 1 ☐ 2 ☐	14 *Upper back* No Yes 1 ☐ 2 ☐	15 *Upper back* No Yes 1 ☐ 2 ☐
16 *Lower back (small of the back)* No Yes 1 ☐ 2 ☐	17 *Lower back* No Yes 1 ☐ 2 ☐	18 *Lower back* No Yes 1 ☐ 2 ☐
19 *Hips/thighs/buttocks (one/both)* No Yes 1 ☐ 2 ☐	20 *Hips/thighs/buttocks* No Yes 1 ☐ 2 ☐	21 *Hips/thighs/buttocks* No Yes 1 ☐ 2 ☐
22 *One or both knees* No Yes 1 ☐ 2 ☐	23 *Knees* No Yes 1 ☐ 2 ☐	24 *Knees* No Yes 1 ☐ 2 ☐
25 *One or both ankles/feet* No Yes 1 ☐ 2 ☐	26 *Ankles/feet* No Yes 1 ☐ 2 ☐	27 *Ankles/feet* No Yes 1 ☐ 2 ☐

Neck trouble

3

How to answer the questionnaire
By neck trouble we mean ache, pain, discomfort or numbness in the shaded area only.

Please answer by using the tick boxes ☑
one tick for each answer.



1 Have you **ever** had any neck trouble (ache, pain,discomfort or numbness)?

No	Yes
1 ☐	2 ☐

If you have answered **NO** to this question do not answer questions 2-10 but please go to the section on **Shoulder trouble** page 4.

2 Have you **ever** hurt your neck in an **accident?**

No	Yes
1 ☐	2 ☐

3 Have you **ever** had to **change duties or jobs** because of neck trouble?

No	Yes
1 ☐	2 ☐

4 What do you think brought on this problem with your neck?

1 ☐ Accident
2 ☐ Sporting activity
3 ☐ Activity at home
4 ☐ Activity at work
5 ☐ Other

(Please state exactly what) ____________________

5 Have you **ever** been absent from work because of neck trouble?

No	Yes
1 ☐	2 ☐

If the answer is **NO**, please go to Question 6

If **YES:**

5a How many **times?** ☐☐

5b How many **days** have you been absent from work with neck trouble **in total?** ☐☐☐

5c How many days have you been absent from work with neck trouble in the **last 12 months?** ☐☐☐

6 When did you **first experience** neck trouble?

Year
19 ☐☐

7 What is the **total length of time** that you have had neck trouble during the **last 12 months?**

1 ☐ 0 days
2 ☐ 1-7 days
3 ☐ 8-30 days
4 ☐ More than 30 days, but not every day
5 ☐ Every day

8 Has neck trouble caused you to **reduce** or change your activities during the **last 12 months?**

	No	Yes
8a Work activity	1 ☐	2 ☐
8b Leisure activity	1 ☐	2 ☐

9 What is the **total length of time** that neck trouble has prevented you from doing your **normal work** (at home or away from home) during the **last 12 months?**

1 ☐ 0 days
2 ☐ 1-7 days
3 ☐ 8-30 days
4 ☐ More than 30 days

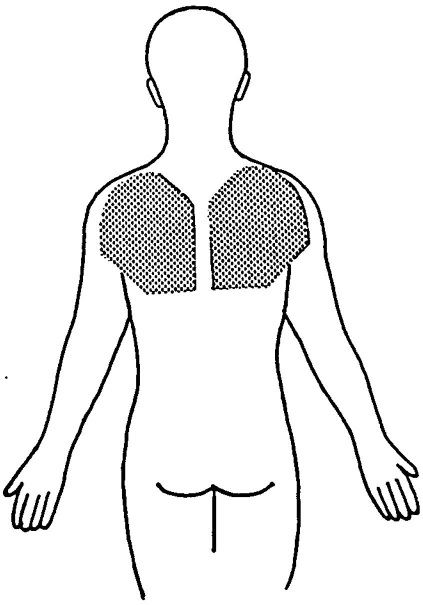
10 Have you been seen by a doctor, physiotherapist, chiropractor or other such person because of neck trouble during the **last 12 months?**

No	Yes
1 ☐	2 ☐

Shoulder trouble

How to answer the questionnaire
By shoulder trouble we mean ache, pain, discomfort or numbness in the shaded area only.

Please answer by using the tick boxes. ☑
one tick for each answer.



1 Have you **ever** had shoulder trouble (ache, pain, numbness or discomfort)?

No	Yes
1☐	2☐

If you have answered NO to this question, do not answer questions 2-10 but please go to the section on Low back trouble on page 5.

2 Have you **ever** hurt your shoulder in an accident?

No	Yes
1☐	2☐

3 Have you **ever** had to **change duties** or **jobs** because of shoulder trouble?

No	Yes
1☐	2☐

4 What do you think brought on this problem with your shoulder?

1☐ Accident
2☐ Sporting activity
3☐ Activity at home
4☐ Activity at work
5☐ Other

(Please state exatcly what) ________________________________
____

5 Have you **ever** been absent from work because of shoulder trouble?

No	Yes
1☐	2☐

If you answered NO, please go to question 6

If YES:

5a How many **times**? ☐☐

5b How many **days** have you been absent from work with shoulder trouble in total? ☐☐☐

5c How many **days** have you been absent from work with shoulder trouble in the **last 12 months?** ☐☐☐

6 When did you **first experience** shoulder trouble?

Year
19☐☐

7 What is the **total length of time** that you have had shoulder trouble during the **last 12 months?**

1☐ 0 days
2☐ 1-7 days
3☐ 8-30 days
4☐ More than 30 days, but not every day
5☐ Every day

8 Has shoulder trouble caused you to **reduce** or change your activities during the **last 12 months?**

	No	Yes
8a Work activity	1☐	2☐
8b Leisure activity	1☐	2☐

9 What is the **total length of time** that shoulder trouble has prevented you from doing your **normal work** (at home or away from home) during the **last 12 months?**

1☐ 0 days
2☐ 1-7 days
3☐ 8-30 days
4☐ More than 30 days

10 Have you been seen by a doctor, physiotherapist, chiropractor or other such person because of shoulder trouble during the **last 12 months?**

No	Yes
1☐	2☐

Low back trouble

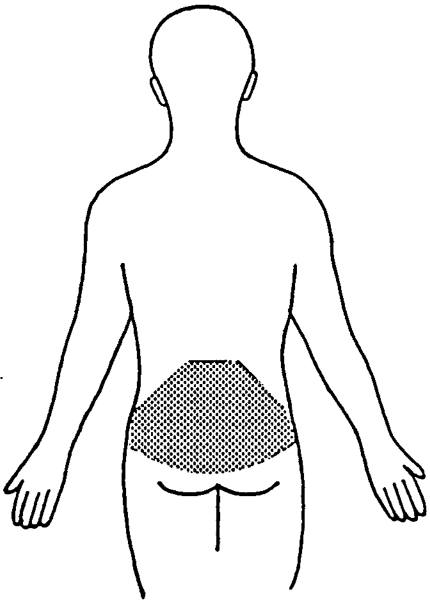
How to answer the questionnaire
By low back trouble we mean ache, pain, discomfort or numbness in the shaded area whether of not it extends from there to one or both legs (sciatica).

Please answer by using the tick boxes. ☑
one tick for each answer.

1 Have you **ever** had any low back trouble (ache, pain, numbness or discomfort)?

No 1 ☐ **Yes** 2 ☐

If you have answered NO to this question, do not answer questions 2-10 but please go to the section on Information about your lifestyle on page 6.



2 Have you **ever** hurt your back in an accident?

No 1 ☐ **Yes** 2 ☐

3 Have you **ever** had to **change duties** or **jobs** because of low back trouble?

No 1 ☐ **Yes** 2 ☐

4 What do you think brought on this problem with your back?

- 1 ☐ Accident
- 2 ☐ Sporting activity
- 3 ☐ Activity at home
- 4 ☐ Activity at work
- 5 ☐ Other

(Please state exactly what) ----------------------------------
----

5 Have you **ever** been absent from work with low back trouble?

No 1 ☐ **Yes** 2 ☐

If you answered NO, please go to question 6

If **YES:**

5a How many **times**? ☐☐

5b How many **days** have you been absent from work with low back trouble in total? ☐☐☐

5c How many **days** have you been absent from work with low back trouble in the **last 12 months?** ☐☐☐

6 When did you **first experience** low back trouble?

Year
19 ☐☐

7 What is the **total length of time** that you have had low back trouble during the **last 12 months?**

- 1 ☐ 0 days
- 2 ☐ 1-7 days
- 3 ☐ 8-30 days
- 4 ☐ More than 30 days, but not every day
- 5 ☐ Every day

8 Has low back trouble caused you to **reduce** or change your activities during the **last 12 months?**

	No	Yes
8a Work activity	1 ☐	2 ☐
8b Leisure activity	1 ☐	2 ☐

9 What is the **total length of time** that low back trouble has prevented you from doing your **normal work** (at home or away from home) during the **last 12 months?**

- 1 ☐ 0 days
- 2 ☐ 1-7 days
- 3 ☐ 8-30 days
- 4 ☐ More than 30 days

10 Have you been seen by a doctor, physiotherapist, chiropractor or other such person because of low back trouble during the **last 12 months?**

No 1 ☐ **Yes** 2 ☐

Information about your lifestyle

1 On average how many hours of **physical exercise** do you take part in **each week?** hours ☐☐☐
This can include gardening, heavy housework and D.I.Y.

2 Which of the following **sporting activities** have you regularly taken part in (if any) over the **last 12 months?** Add any **other** sporting activities at the end.

		Number of **hours per week** during:		
	Sporting activity	summer	winter	
a.	Rugby	▨	▨	☐☐
b.	High Intensity Aerobics	▨	▨	☐☐
c.	Squash	▨	▨	☐☐
d.	Weights	▨	▨	☐☐
e.	Jogging	▨	▨	☐☐
f.	Football	▨	▨	☐☐
g.	Horseriding	▨	▨	☐☐
h.	Gymnastics	▨	▨	☐☐
i.	Golf	▨	▨	☐☐
j.	Martial Arts	▨	▨	☐☐
k.	Windsurfing	▨	▨	☐☐
l.	Cricket	▨	▨	☐☐
m.	Rowing	▨	▨	☐☐
n.	Power boating	▨	▨	☐☐
o.	Ski-ing	▨	▨	☐☐
o.	Tennis	▨	▨	☐☐
q.	Athletics	▨	▨	☐☐
r.	Badminton	▨	▨	☐☐
s.	Sailing	▨	▨	☐☐
t.	Others (Please list) ▨	▨	▨	☐☐

3 Are you a **cigarette smoker?** No 1☐ Yes 2☐ No reply 3☐

3a If you answered **YES** how many cigarettes do you **smoke a day**? ☐☐

Information about your job

1 Please list **ALL occupations** held for more than **12 months** since leaving school?

Occupation	**Number of years**	**Average hours per week for each**	**Hours driving per week** (if more than 4 hours)

If you have not worked for more than 12 months please go on to Section 2 page 13

If you have stopped working **within the last 12 months** answer questions **2** to **9** as if for your last job

2 What is your **current** occupation? ______________________ ☐☐☐

3 How many hours in a typical week do you **currently** work? **Hours** ☐☐☐

4 How would you describe your level of job satisfaction?

Satisfied	1	☐
Partially satisfied	2	☐
No feelings either way	3	☐
Not satisfied	4	☐
Would like a change	5	☐

5 How **far** is your journey to work? **Miles** ☐ or **Km** ☐☐☐☐

6 How do you **normally travel** to work?

Walk	1	☐
Cycle	2	☐
Public transport Eg train, bus.	3	☐
Drive yourself by car	4	☐
Other	5	☐

7 How **long** does this journey usually take you? **Hours** ☐☐ **Minutes** ☐☐

8 Do your **activities** (work and leisure) in a typical week over the **last 12 months** involve any of the following?

		Work	Leisure
a. Sitting	Often (more than 4 hours per day)	1 ☐	1 ☐
	Sometimes	2 ☐	2 ☐
	Rarely (less than 2 hours per day)	3 ☐	3 ☐
b. Standing	Often (more than 4 hours per day)	1 ☐	1 ☐
	Sometimes	2 ☐	2 ☐
	Rarely (less than 2 hours per day)	3 ☐	3 ☐
c. Lifting (5Kg or more)	Often (more than 10 times an hour)	1 ☐	1 ☐
	Sometimes	2 ☐	2 ☐
	Rarely or never	3 ☐	3 ☐
d. Sudden maximal physical effort	Often	1 ☐	1 ☐
	Sometimes	2 ☐	2 ☐
	Rarely or never	3 ☐	3 ☐
e. Exposure to Vibration	Often (more than 4 hours per day)	1 ☐	1 ☐
	Sometimes	2 ☐	2 ☐
	Rarely or never	3 ☐	3 ☐

	No	Yes
9 In a **typical week** do you drive for more than 4 hours as part of **your work?**	1 ☐	2 ☐

If you answered **YES** to question 9 please answer **Section 1 ONLY** on page **9**

If you answered **NO** to question 9 please answer **Section 2 ONLY** on page **13**

Section 1

☐8

1 List up to **2 main vehicles** driven as part of **your work**?

	Make	Model	Year	Yr letter
Vehicle 1			19☐☐	___
Vehicle 2			19☐☐	___

☐☐☐☐

2 On average how many **hours** each week do you drive as part of **your work**?

Hours ☐☐ **Minutes** ☐☐

3 On average how **far** do you drive each week as part of **your work**?

Miles ☐ or **Km** ☐☐☐☐

4 What is your **total mileage** on the road each year (including **private mileage**)?

Miles ☐ or **Km** ☐☐☐☐☐☐

5 Which of these best describes the type of **driving** that you do **for work**?

Mainly motorway	1 ☐
Mainly town	2 ☐
Mainly open road	3 ☐
A combination of the above	4 ☐
Off road (fields, track, lanes)	5 ☐

6 Have you **ever** experienced any **discomfort** when driving each of the vehicles that you have named above?

	Vehicle 1	**Vehicle 2**
Always	1 ☐	1 ☐
Often	2 ☐	2 ☐
Sometimes e.g. long journeys	3 ☐	3 ☐
Rarely	4 ☐	4 ☐
Never	5 ☐	5 ☐

If you do experience discomfort, please explain **where on your body** it occurs e.g. buttocks and under **what circumstances** e.g. motorway driving?

	Body area	**Under what circumstances**
Vehicle 1		
Vehicle 2		

7 Please answer the following questions for **each vehicle** that you have named in question 1

Vehicle 1

a. Does this **vehicle** have any of the following features?

	No	**Yes**	**Don't know**
Seat height adjustment	1 ☐	2 ☐	3 ☐
Seat pan adjustment	1 ☐	2 ☐	3 ☐
Backrest angle adjustment	1 ☐	2 ☐	3 ☐
Lumbar support adjustment	1 ☐	2 ☐	3 ☐
Steering wheel adjustment	1 ☐	2 ☐	3 ☐
Automatic gearbox	1 ☐	2 ☐	3 ☐
Sun roof	1 ☐	2 ☐	3 ☐
Cruise control	1 ☐	2 ☐	☐

	No	**Yes**	**Don't know**
b. Do you have enough **headroom** in this vehicle?	1 ☐	2 ☐	3 ☐
c. Are the **pedals** in a comfortable position?	1 ☐	2 ☐	3 ☐
d. Is the **steering wheel** in a comfortable position?	1 ☐	2 ☐	3 ☐

Vehicle 2

a. Does this **vehicle** have any of the following features?

	No	**Yes**	**Don't know**
Seat height adjustment	1 ☐	2 ☐	3 ☐
Seat pan adjustment	1 ☐	2 ☐	3 ☐
Backrest angle adjustment	1 ☐	2 ☐	3 ☐
Lumbar support adjustment	1 ☐	2 ☐	3 ☐
Steering wheel adjustment	1 ☐	2 ☐	3 ☐
Automatic gearbox	1 ☐	2 ☐	3 ☐
Sun roof	1 ☐	2 ☐	3 ☐
Cruise control	1 ☐	2 ☐	3 ☐

	No	**Yes**	**Don't know**
b. Do you have enough **headroom** in this vehicle?	1 ☐	2 ☐	3 ☐
c. Are the **pedals** in a comfortable position?	1 ☐	2 ☐	3 ☐
d. Is the **steering wheel** in a comfortable position?	1 ☐	2 ☐	3 ☐

8 List up to 2 **main vehicles** that you drive for **private mileage**?

	Make	Model	Year	Yr letter
Vehicle 1			19☐☐	___
Vehicle 2			19☐☐	___

☐☐☐☐

If any of these vehicles are **different** to those listed in **question 1** please answer **questions 9-13**

If these vehicles are the **same** as those listed in **question 1** please go to **page 15**

9 Have you **ever** experienced any **discomfort** when driving each of the vehicles that you have named above?

	Vehicle 1	**Vehicle 2**
Always	1 ☐	1 ☐
Often	2 ☐	2 ☐
Sometimes e.g. long journeys	3 ☐	3 ☐
Rarely	4 ☐	4 ☐
Never	5 ☐	5 ☐

If you do experience discomfort, please explain **where on your body** it occurs e.g. buttocks and under **what circumstances** e.g. motorway driving?

	Body area	**Under what circumstances**
Vehicle 1		
Vehicle 2		

10 Please answer the following questions for **each vehicle** that you have named in question 8

Vehicle 1

a. Does this **vehicle** have any of the following features?

	No	**Yes**	**Don't know**
Seat height adjustment	1☐	2☐	3☐
Seat pan adjustment	1☐	2☐	3☐
Backrest angle adjustment	1☐	2☐	3☐
Lumbar support adjustment	1☐	2☐	3☐
Steering wheel adjustment	1☐	2☐	3☐
Automatic gearbox	1☐	2☐	3☐
Sun roof	1☐	2☐	3☐
Cruise control	1☐	2☐	3☐

	No	**Yes**	**Don't know**
b. Do you have enough **headroom** in this vehicle?	1☐	2☐	3☐
c. Are the **pedals** in a comfortable position?	1☐	2☐	3☐
d. Is the **steering wheel** in a comfortable position?	1☐	2☐	3☐

Vehicle 2

a. Does this **vehicle** have any of the following features?

	No	**Yes**	**Don't know**
Seat height adjustment	1☐	2☐	3☐
Seat pan adjustment	1☐	2☐	3☐
Backrest angle adjustment	1☐	2☐	3☐
Lumbar support adjustment	1☐	2☐	3☐
Steering wheel adjustment	1☐	2☐	3☐
Automatic gearbox	1☐	2☐	3☐
Sun roof	1☐	2☐	3☐
Cruise control	1☐	2☐	3☐

	No	**Yes**	**Don't know**
b. Do you have enough **headroom** in this vehicle?	1☐	2☐	3☐
c. Are the **pedals** in a comfortable position?	1☐	2☐	3☐
d. Is the **steering wheel** in a comfortable position?	1☐	2☐	3☐

You have now completed the questionnaire

10

Section 2

		Yes	No
1	Do you hold a **driving license?**	1 ☐	2 ☐

If you answered NO to question 1 please go to the end of the questionnaire

If you answered YES to question 1 please answer questions 2 -8

		Miles		Km
2	What was your total mileage during the **last 12 months?**	☐	or	☐☐☐☐☐☐

3 List up to 2 **main vehicles** that you drive for private mileage?

	Make	Model	Year	Yr letter
Vehicle 1	▨	▨	19 ☐☐	___
Vehicle 2	▨	▨	19 ☐☐	___
			☐☐☐☐	

		Hours	Minutes
4	On average how many **hours** each week do you drive?	☐☐	☐☐

		Miles	Km
5	On average how **far** do you drive each week?	☐	☐☐☐☐

6 Which of these best describes the type of **driving** that you do?

Mainly motorway	1 ☐
Mainly town	2 ☐
Mainly open road	3 ☐
A combination of the above	4 ☐
Off road (fields, track, lanes)	5 ☐

7 Have you **ever** experienced any **discomfort** when driving each of the vehicles that you have named above?

	Vehicle 1	**Vehicle 2**
Always	1 ☐	1 ☐
Often	2 ☐	2 ☐
Sometimes e.g. long journeys	3 ☐	3 ☐
Rarely	4 ☐	4 ☐
Never	5 ☐	5 ☐

If you do experience discomfort, please explain **where on your body** it occurs e.g. buttocks and under **what circumstances** e.g. motorway driving?

	Body area	**Under what circumstances**
Vehicle 1		
Vehicle 2		

8 Please answer the following questions for **each vehicle** that you have named in question 7

Vehicle 1

a. Does this **vehicle** have any of the following features?

	No	**Yes**	**Don't know**
Seat height adjustment	1 ☐	2 ☐	3 ☐
Seat pan adjustment	1 ☐	2 ☐	3 ☐
Backrest angle adjustment	1 ☐	2 ☐	3 ☐
Lumbar support adjustment	1 ☐	2 ☐	3 ☐
Steering wheel adjustment	1 ☐	2 ☐	3 ☐
Automatic gearbox	1 ☐	2 ☐	3 ☐
Sun roof	1 ☐	2 ☐	3 ☐
Cruise control	1 ☐	2 ☐	3 ☐

	No	**Yes**	**Don't know**
b. Do you have enough **headroom** in this vehicle?	1 ☐	2 ☐	3 ☐
c. Are the **pedals** in a comfortable position?	1 ☐	2 ☐	3 ☐
d. Is the **steering wheel** in a comfortable position?	1 ☐	2 ☐	3 ☐

Vehicle 2

a. Does this **vehicle** have any of the following features?

	No	Yes	Don't know
Seat height adjustment	1 ☐	2 ☐	3 ☐
Seat pan adjustment	1 ☐	2 ☐	3 ☐
Backrest angle adjustment	1 ☐	2 ☐	3 ☐
Lumbar support adjustment	1 ☐	2 ☐	3 ☐
Steering wheel adjustment	1 ☐	2 ☐	3 ☐
Automatic gearbox	1 ☐	2 ☐	3 ☐
Sun roof	1 ☐	2 ☐	3 ☐
Cruise control	1 ☐	2 ☐	3 ☐

	No	Yes	Don't know
b. Do you have enough **headroom** in this vehicle?	1 ☐	2 ☐	3 ☐
c. Are the **pedals** in a comfortable position?	1 ☐	2 ☐	3 ☐
d. Is the **steering wheel** in a comfortable position?	1 ☐	2 ☐	3 ☐

You have now completed the questionnaire.

Thank you very much for your time.

Appendix 2

Prevalence and Sickness Absence Data (General Public)

The prevalence and severity of neck, shoulder and low back trouble as a percentage of the sample of the general public (n=600).

Trouble	**Whole sample** (n=600)	**Males** (n=303)	**Females** (297)
Point prevalence (7 days) of **neck trouble.**	13%	7%	19%
Period prevalence (12 months) of **neck trouble.**	32%	27%	37%
Severity of **neck trouble** (12 months).	8%	5%	10%
Lifetime prevalence of **neck trouble.**	39%	36%	43%
Point prevalence (7 days) of **shoulder trouble.**	13%	9%	17%
Period prevalence (12 months) of **shoulder trouble.**	27%	23%	31%
Severity of **shoulder trouble** (12 months).	7%	5%	9%
Lifetime prevalence of **shoulder trouble.**	33%	28%	37%
Point prevalence (7 days) of **low back trouble.**	24%	22%	26%
Period prevalence (12 months) of **low back trouble.**	47%	48%	47%
Severity of **low back trouble** (12 months).	14%	15%	13%
Lifetime prevalence of **low back trouble.**	56%	56%	57%

Sickness absence descriptive statistics for the sample of the general public (n=600).

Trouble	Whole sample (n=600) Mean (SD) Range	Males (n=303) Mean (SD) Range	Females (n=297) Mean (SD) Range
The number of occasions ever absent from work with **neck trouble.**	0.13 (0.45) 0-4	0.1 (0.4) 0-4	0.16 (0.5) 0-3
Total number of days ever absent from work with **neck trouble.**	2.06 (12.16) 0-180	2.15 (14.84) 0-180	2 (8.65) 0-80
Total number of days absent from work with **neck trouble** in the last 12 months.	0.56 (4.56) 0-60	0.27 (3.07) 0-50	0.85 (5.68) 0-60
The number of occasions ever absent from work with **shoulder trouble.**	0.06 (0.35) 0-5	0.05 (0.38) 0-5	0.07 (0.31) 0-2
Total number of days ever absent from work with **shoulder trouble.**	1.15 (8.73) 0-150	0.87 (9.24) 0-150	1.44 (8.18) 0-80
Total number of days absent from work with **shoulder trouble** in the last 12 months.	0.43 (4.23) 0-60	0.22 (3.0) 0-50	0.64 (5.2) 0-60
The number of occasions ever absent from work with **low back trouble.**	0.51 (1.81) 0-24	0.47 (1.39) 0-15	0.54 (2.18) 0-24
Total number of days ever absent from work with **low back trouble.**	7.1 (35.9) 0-600	7.61 (40.21) 0-600	6.58 (30.95) 0-369
Total number of days absent from work with **low back trouble** in the last 12 months.	0.58 (3.41) 0-50	0.61 (3.59) 0-50	0.55 (3.21) 0-30

Appendix 3

Prevalence Odds Ratios

Prevalence odds ratios for low back trouble and exposure to driving cars.

Low back trouble	**Sitting>4** hours/day cf. not.	**Standing>4** hours/day cf. not.	**Lifting** more than 5 Kg regularly cf. not.	Exposure to whole body **vibration** cf. not.	Exposure to regular maximal **physical exertion**	Cigarette **smokers** cf. non-smokers	Partake in 10 **'risk sports'** cf. not.
Point prevalence (7 days)	0.94	0.80	1.26	0.51	0.89	0.88	0.90
Period prevalence (12 months)	1.01	0.90	1.59	1.15	1.24	1.36	0.93
Lifetime prevalence	0.87	0.83	1.19	0.97	1.10	1.17	0.80
Severity (12 months)	1.07	1.23	1.76	1.13	3.20	1.47	0.88

Appendix 4

Descriptive Statistics for Driver Groups

Descriptive statistics for the samples of non-drivers, social domestic and pleasure (S,D & P) car drivers and subjects who drive cars as part of their job.

Variable	Non-drivers (n=135)	S, D & P car drivers (n=309)	Drive cars as part of their job (n=113)	Sig
Sex (males, females)	32% , 68%	46%, 54%	70%, 30%	-
Age - mean (SD)	36.0 (15.4)	39.32 (13.61)	39.3 (10.2)	*
Employed - yes	52%	67%	100%	-
Smokers - yes	32%	19%	20%	***
Total risk sports (hours), mean (SD)	1.72 (3.5)	2.06 (4.23)	2.6 (5.9)	NS
Point prevalence (7 days) of low back trouble.	25%	23%	30%	NS
Period prevalence (12 months) of low back trouble.	46%	45%	55%	NS
Lifetime prevalence of low back trouble.	55%	55%	61%	NS
(Mean, SD)	**Workers only (n=70)**	**Workers only (n=207)**	**All Workers (n=113)**	
Total days ever absent from work with low back trouble.	1.66 (4.7)	4.96 (16.73)	16.2 (67.3)	**
Number of occasions ever absent from work with low back trouble.	0.23 (1.1)	0.46 (1.17)	0.78 (2.6)	(a)
Total number of days ever absent with low back trouble in the last 12 months.	0.26 (1.18)	0.53 (2.35)	0.49 (2.8)	NS

N.B. NS = Not Significant, (a)=0.1>p>0.05, * p<0.05, ** p<0.01, *** p<0.001.

Appendix 5

The Structure of Sussex Constabulary

The Structure of Sussex Constabulary

Sussex police is divided into 15 Divisions representing different geographical area, Headquarters and 8 Traffic Divisions. The breakdown in numbers of the establishment (March 1993) was as follows:-

Total establishment	3014 (not including Civilians)
Traffic Division	250
W1 Chichester	123
W2 Arun	138
W3 Worthing	115
W4 Shoreham	77
N1 Crawley	113
N2 Horsham	86
N3 Mid-Sussex	85
N4 East Grinstead	106
G1 Gatwick	252
C1 Brighton	312
C2 Hove	120
E1 Hastings	118
E2 Rother	104
E3 Lewes	104
E4 Eastbourne	169

At that time there were approximately 1000 civilians employed in a variety of different occupations for example administration, Traffic Wardens, vehicle workshops and health.

The Shift System

At the time of the survey Sussex Constabulary used the OTOWA shift system. They worked an eight hour shift and over three shifts they could work and extra two hours overtime. The shift times were as follows:-

Earlies	6.00 am - 2.00 pm
Lates	2.00 pm - 10.00 pm
Nights	10.00 pm - 6.00 am

They worked blocks of seven days on earlies, lates and nights. They worked 21 out of 28 days; eight days being the maximum number of days in a row. The shifts were not flexible and once allocated a shift they must follow it, rotating shifts with the same group of people. Any time owed could be taken as lieu days or overtime.

Reporting Sickness Absence

Only the whole days of sickness were recorded but could be divided in 'working days lost' and total days lost'. The classification was as follows:-

up to 3 days - Uncertified Leave.
up to 7 days - Self Certification.
8 days and over - a doctors certificate was needed but no pay was lost.

Previously there was little follow-up of long term sickness and it could last almost indefinitely. At Sussex Constabulary, after 28 days the employee appeared on the long term sick list. If the 'sickness reason' was obvious such as a fracture no action was taken. If there was concern for example stress-related sickness, the Occupational Health Nurse wrote to the Divisional Commander for a full report and if there was still concern and review date was decided. The review process may then continue periodically until perhaps it was decided to retire and individual on medical grounds. All police officers have to retire after 35 years service.

Appendix 6

Prevalence and Sickness Absence Data (The Police)

The prevalence and severity of neck, shoulder and low back trouble as a percentage of the sample of police officers (n=200).

Trouble	**Whole sample** (n=200)	**Traffic** (n=105)	**Gatwick & HQ** (n=95)
Point prevalence (7 days) of **neck trouble.**	12%	12%	11%
Period prevalence (12 months) of **neck trouble.**	31%	29%	33%
Severity of **neck trouble** (12 months).	8%	10%	6%
Lifetime prevalence of **neck trouble.**	47%	46%	48%
Point prevalence (7 days) of **shoulder trouble.**	10%	12%	6%
Period prevalence (12 months) of **shoulder trouble.**	26%	31%	19%
Severity of **shoulder trouble** (12 months).	8%	10%	5%
Lifetime prevalence of **shoulder trouble.**	33%	39%	25%
Point prevalence (7 days) of **low back trouble.**	20%	19%	21%
Period prevalence (12 months) of **low back trouble.**	49%	46%	53%
Severity of **low back trouble** (12 months).	16%	17%	15%
Lifetime prevalence of **low back trouble.**	66%	65%	66%

Sickness absence descriptive statistics for the sample of police officers (n=200).

Trouble	**Whole sample** (n=200) Mean (SD) Range	**Traffic** (n=105) Mean (SD) Range	**Gatwick & HQ** (n=95) Mean (SD) Range
The number of occasions ever absent from work with **neck trouble.**	0.35 (0.95) 0-7	0.39 (1.1) 0-7	0.31 (0.76) 0-6
Total number of days ever absent from work with **neck trouble.**	7.29 (26.18) 0-250	9.86 (33.24) 0-250	4.45 (14.59) 0-90
Total number of days absent from work with **neck trouble** in the last 12 months.	1.24 (6.92) 0-75	1.77 (9.16) 0-75	0.64 (2.81) 0-18
The number of occasions ever absent from work with **shoulder trouble.**	0.15 (0.6) 0-6	0.16 (0.48) 0-3	0.13 (0.7) 0-6
Total number of days ever absent from work with **shoulder trouble.**	3.17 (15.36) 0-150	3.47 (13.93) 0-102	2.84 (16.86) 0-150
Total number of days absent from work with **shoulder trouble** in the last 12 months.	0.93 (6.9) 0-75	1.56 (9.31) 0-75	0.23 (1.89) 0-18
The number of occasions ever absent from work with **low back trouble.**	0.68 (1.87) 0-20	0.67 (2.22) 0-20	0.69 (1.4) 0-8
Total number of days ever absent from work with **low back trouble.**	9.8 (29.97) 0-250	11.65 (34.71) 0-250	7.76 (23.68) 0-184
Total number of days absent from work with **low back trouble** in the last 12 months.	1.68 (8.16) 0-75	2.55 (10.81) 0-75	0.72 (3.14) 0-20

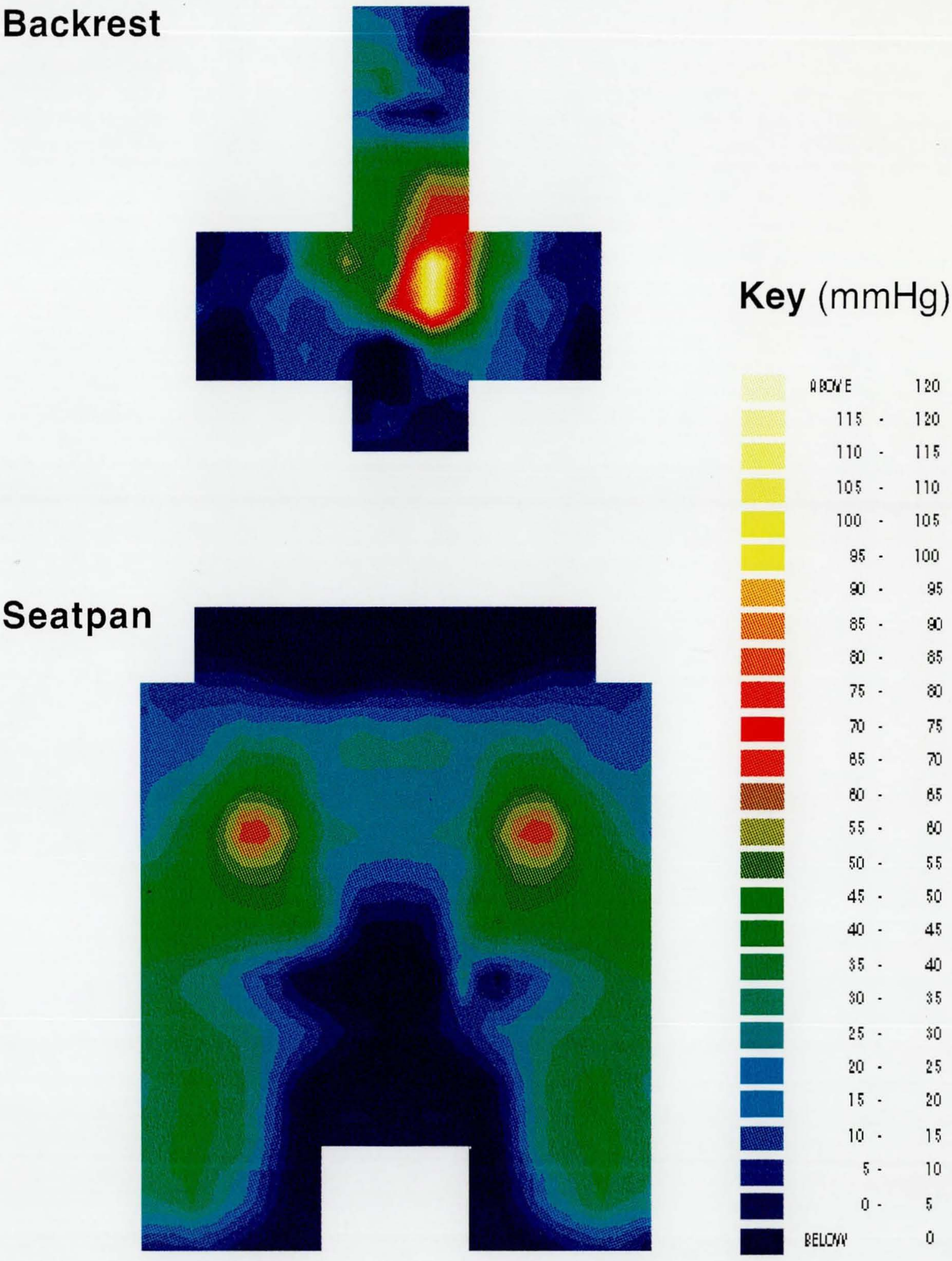
Appendix 7

Examples of Pressure Maps

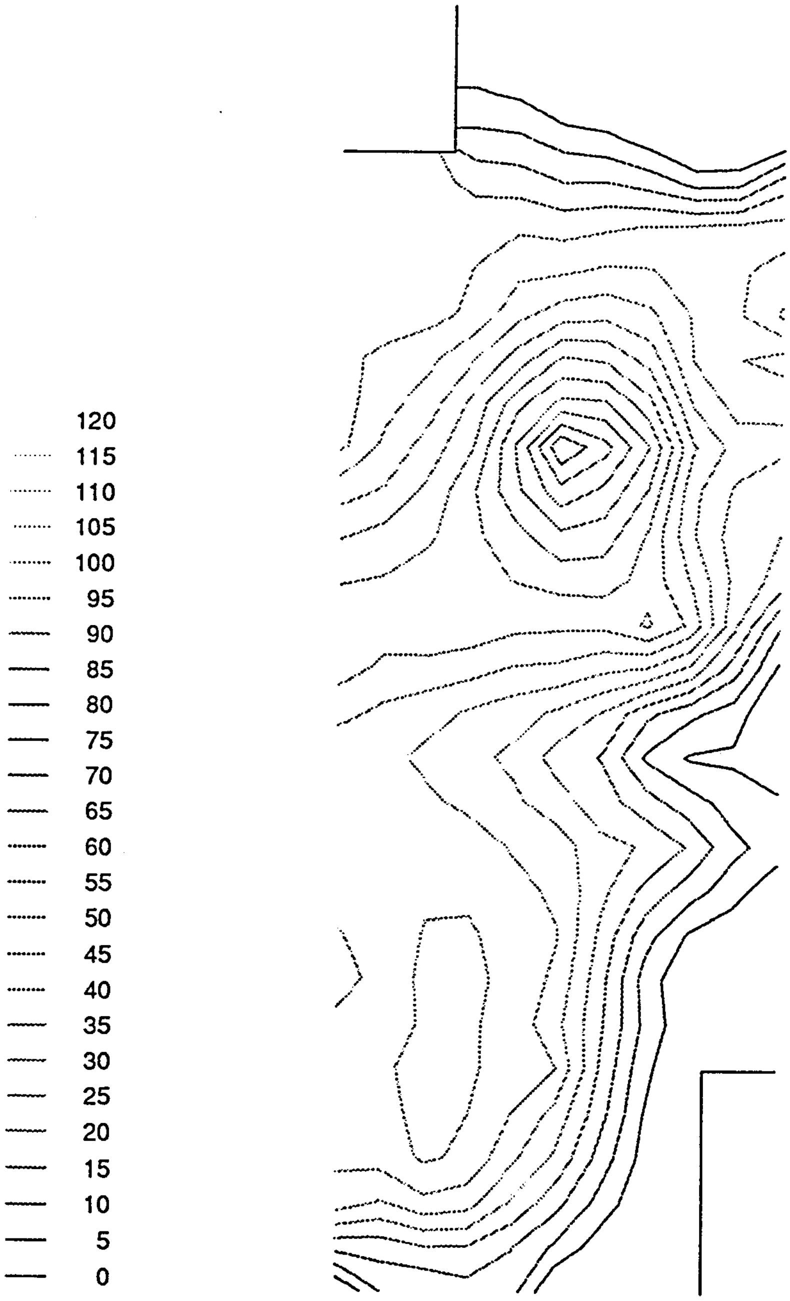
Car seat pressure distribution maps

Subject number 6 - Male

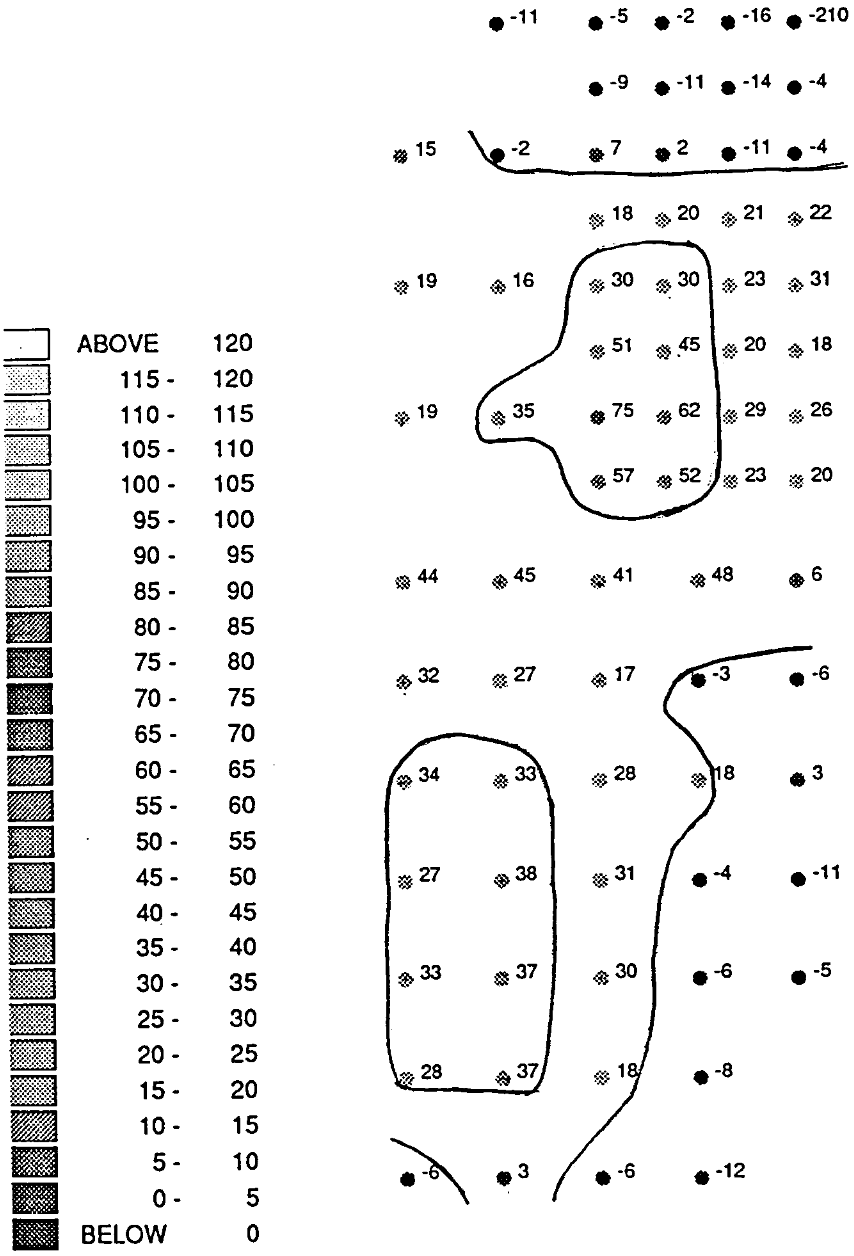
Least preferred seat



06s2seat


120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

06s2seat


ABOVE 120
115 - 120
110 - 115
105 - 110
100 - 105
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
BELOW 0
-11 -5 -2 -16 -210
-9 -11 -14 -4
15 -2 7 2 -11 -4
18 20 21 22
19 16 30 30 23 31
51 45 20 18
19 35 75 62 29 26
57 52 23 20
44 45 41 48 6
32 27 17 -3 -6
34 33 28 18 3
27 38 31 -4 -11
33 37 30 -6 -5
28 37 18 -8
-6 3 -6 -12

Appendix 8

Interface Pressure Variables

The Interface Pressure Variables Initially Calculated.

Variable	Description
Whole Seat	
Seat Maximum	Maximum pressure value in defined seat area
Seat Mean	Mean pressure in defined seat area
Seat Standard Deviation	The Standard Deviation from the mean in the defined seat
Seat Total	The sum of the cells in the defined seat area
Average Seat Ratio	Ratio between Seat Mean and Back Mean
Right Ischial Tuberosity (IT)	
IT Maximum	Maximum pressure value in the defined IT area (9 cells)
IT Mean	Mean pressure in the defined IT area (9 cells)
IT Standard Deviation	The Standard Deviation from the mean in the defined IT area
IT Total	The sum of the cells in the defined IT area (9 cells)
IT Ratio Maximum	Minimum value / Maximum value in defined IT area (9 cells)
IT Ratio Minimum	The second highest pressure value / Maximum value in the defined IT area (9 cells)
IT Proportion	IT Total / Seat Total
Right Thigh	
Thigh Maximum	Maximum pressure value in the defined thigh area (8 cells)
Thigh Mean	Mean pressure value in the defined thigh area (8 cells)
Thigh Standard Deviation	The Standard Deviation from the mean in the defined thigh area (8 cells)
Thigh Total	The sum of the cells in the defined thigh area (8 cells)
Thigh Ratio Maximum	Minimum value / Maximum value in the defined thigh area (8 cells)
Thigh Ratio Minimum	The second highest pressure value / Maximum value in the defined thigh area (8 cells)
Thigh Proportion	Thigh Total / Seat Total
Low Back	
Back Maximum	Maximum pressure value in the defined back area
Back Mean	Mean pressure in the defined back area
Back Standard Deviation	The Standard Deviation from the mean in the defined back area
Back Total	The sum of the cells in the defined back area
Back Ratio Maximum	Minimum value / Maximum value in the defined back area
Back Ratio Minimum	The second highest pressure value / Maximum value in the defined back area

Appendix 9

Anthropometric Data (Experiment 1)

Anthropometric Data (Experiment 1)

	Sample (n=56) Mean (SD) Range	Males (n=28) Mean (SD) Range (%)	Females (n=28) Mean (SD) Range (%)
Stature (mm)	1708 (110) 1475-2002	1792 (79) 1645-2002 (8-99)	1623 (62) 1475-1753 (2-99)
Weight (kg)	74 (16) 38-125	78 (11) 58-104 (8-99)	70 (19) 38-125 (2-99)
Sitting height (mm)	900 (52) 783-1018	937 (36) 855-1018 (6-99)	862 (36) 783-932 (3-99)
Buttock knee length (mm)	606 (43) 524-692	622 (37) 554-692 (9-99)	588 (42) 524-663 (6-99)
Knee height (mm)	522 (39) 444-627	548 (34) 493-627 (5-99)	495 (24) 444-551 (2-97)
Hip breadth (mm)	380 (39) 297-512	371 (21) 321-410 (9-96)	389 (50) 297-512 (2-99)
Upper limb length (mm)	756 (59) 637-910	798 (49) 710-910 (3-99)	714 (33) 637-770 (2-98)

SD = Standard Deviation
% = Percentile value for British adults (Pheasant, 1990)

Appendix 10

Seat Feature Checklist

2 D. Seat Feature Checklist

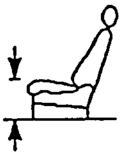
	Yes	No
1. Does your seat offer adequate lateral (side to side) support?	1	2
2. Is the seat covering material to your satisfaction? (If not please give details)	1	2

3. Please look at the following diagrams of the seat and indicate your opinion.

The seat cushion needs to be:

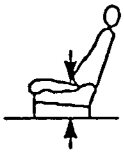
a.

Higher	1
Lower	2
As exists	3



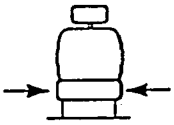
b.

Higher	1
Lower	2
As exists	3



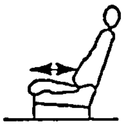
c.

Wider	1
Narrower	2
As exists	3



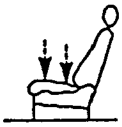
d.

Longer	1
Shorter	2
As exists	3



e.

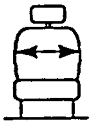
Firmer	1
Softer	2
As exists	3



The seat back needs to be:

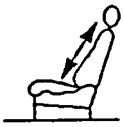
f.

Wider	1
Narrower	2
As exists	3



g.

Longer	1
Shorter	2
As exists	3



h.

Firmer	1
Softer	2
As exists	3

The lumbar support needs to be:

i.

More pronounced	1
Less pronounced	2
As exists	3

j.

Higher	1
Lower	2
As exists	3

Appendix 11

Motor Vehicle Dimensions

Motor vehicle dimensions compared with driving rig measurements.

	Car		H-point values				
Make	Model	Class	L11	L40	L53	H30	H17
Fiat	Uno 1000s	Supermini	349.5	25	783	296	655
Citroen	AX	Supermini	414	25	826	244	620
Peugeot	106	Supermini	464	25	879	231	608
Peugeot	205	Supermini	438	25	865	260	632
Renault	Clio	Supermini	407	25	835	280	653
Renault	5	Supermini	368.5	25	775	298	669
VW	Polo 90	Supermini	423	25	809	274	642
Ford	Fiesta 89	Supermini	412	24	817	266	637
Mazda	121	Supermini	347	25	773	313	672
Fiat	Cinquecento	Supermini	301	25	751	313	680
Opel	Corsa	Small family	452	25	852	260	633
Fiat	Tipo	Small family	350	25	795	302	671
VW	Golf 3(3P)	Small family	410	25	833	280	635
Opel	Astra (5P)	Small family	426	25	817	304	674
Citroen	ZX	Small family	460	25	902	250	620
Renault	19	Small family	418	25	877	282	657
Ford	Escort (93)	Small family	409	25	808	266	641
Alfa	33	Small family	363	25	812	238	624
Rover	200	Small family	437	25	860	240	620
BMW	3 SW	Large family	400	25	792	252	640
Fiat	Tempra	Large family	350	25	795	302	671
Volvo	850	Executive	451	25	837	264	665
Alfa	164	Executive	334	25	769	270	645
Peugeot	605	Executive	455	25	900	254	633
Lancia	Thema	Executive	397	25	849	278	650.5
Rover	800	Executive	429	25	843	240	614
Saab	9000	Executive	424	25	836	281	651
Citroen	XM	Executive	426	25	855	265	650
Renault	Safrane	Executive	414	25	855	285	668
Ford	Scorpio SW	Executive	435	25	858	271	632
BMW	5 SW (525)	Executive	439	25	852	247	637
Audi	100 Avant	Executive	455	25	864	291	655
Rig Values							
Mean Rig			437.7	15.9	738	301.1	627.8
Max Rig			602	25	889	335	689
Min Rig			322	5	577	283	580
SD Rig			47.61	4	67.49	11.28	23.99

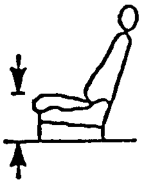
Appendix 12

Seat Feature Checklist Results

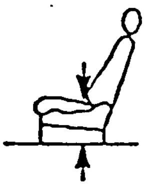
Seat Feature Checklist Results

The seat cushion needs to be (%):-

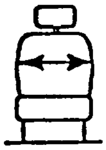
a.	S	M	F
Higher	7	10	5
Lower	7	14	0
As exists	86	76	95



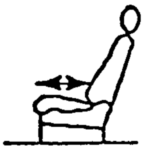
b.	S	M	F
Higher	14	19	10
Lower As	10	19	0
exists	76	62	90



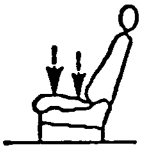
c.			
Wider	33	43	24
Narrower	2	0	5
As exists	65	57	71



d.			
Longer	62	81	43
Shorter	0	0	0
As exists	38	19	57

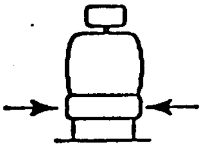


e.			
Firmer	19	29	10
Softer	14	14	14
As exists	67	57	76

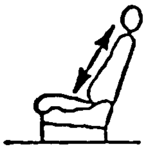


The seat back needs to be (%):-

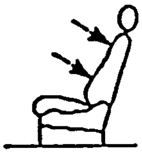
f.	S	M	F
Wider	26	24	29
Narrower	17	19	14
As exists	57	57	57



g.	S	M	F
Longer	10	19	0
Shorter	7	5	10
As exists	83	76	90

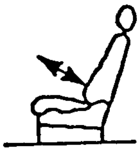


h.	S	M	F
Firmer	14	19	10
Softer	12	10	14
As exists	74	71	76

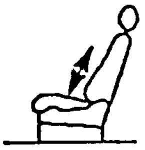


The lumbar support needs to be (%):-

i.	S	M	F
More pronounced	14	19	10
Less pronounced	5	5	5
As exists	81	76	85



j.	S	M	F
Higher	19	24	14
Lower	19	24	14
As exists	62	52	72



S =% of the whole sample (n=42).
M =% of males (n=21).
F =% of females (n=21).

Appendix 13

Method of Paired Comparisons Data Sheet

1

A. Paired comparisons

Please make your assessment of the 21 possible pairings of the 7 seats in the following order, starting where indicated. Enter the number of your preferred seat in each of the 3 columns.

Pair	Seat cushion	Seat back	Whole seat
1 2			
2 3			
3 4			
4 5			
5 6			
6 7			
1 3			
2 4			
3 5			
4 6			
5 7			
1 4			
2 5			
3 6			
4 7			
1 5			
2 6			
3 7			
1 6			
2 7			
1 7			

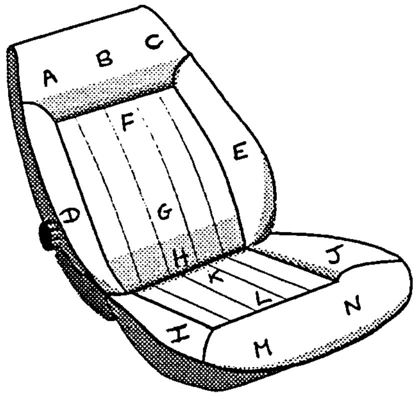
1. **Best seat:**
2. **Worst seat:**

Appendix 14

Seat Detail and Body Part Comfort / Discomfort Questionnaires

2 E. Seat Detail 1

Each part of the seat is shown in the diagram below, please indicate your opinion on how you predict the seat will feel after 2 hours driving.

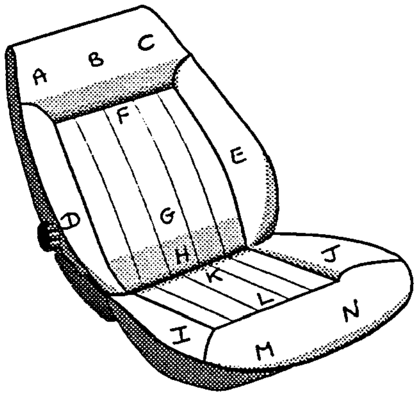


	Section A			Section B		
	Too hard	Just right	Too soft	Over supportive	Support just right	Under supportive
A	1	2	3	1	2	3
B	1	2	3	1	2	3
C	1	2	3	1	2	3
D	1	2	3	1	2	3
E	1	2	3	1	2	3
F	1	2	3	1	2	3
G	1	2	3	1	2	3
H	1	2	3	1	2	3
I	1	2	3	1	2	3
J	1	2	3	1	2	3
K	1	2	3	1	2	3
L	1	2	3	1	2	3
M	1	2	3	1	2	3
N	1	2	3	1	2	3

3
4

Q. Seat Detail 2

Each part of the seat is shown in the diagram below, please indicate your opinion on how the seat feels now.



	Section A			Section B		
	Too hard	Just right	Too soft	Over supportive	Support just right	Under supportive
A	1	2	3	1	2	3
B	1	2	3	1	2	3
C	1	2	3	1	2	3
D	1	2	3	1	2	3
E	1	2	3	1	2	3
F	1	2	3	1	2	3
G	1	2	3	1	2	3
H	1	2	3	1	2	3
I	1	2	3	1	2	3
J	1	2	3	1	2	3
K	1	2	3	1	2	3
L	1	2	3	1	2	3
M	1	2	3	1	2	3
N	1	2	3	1	2	3

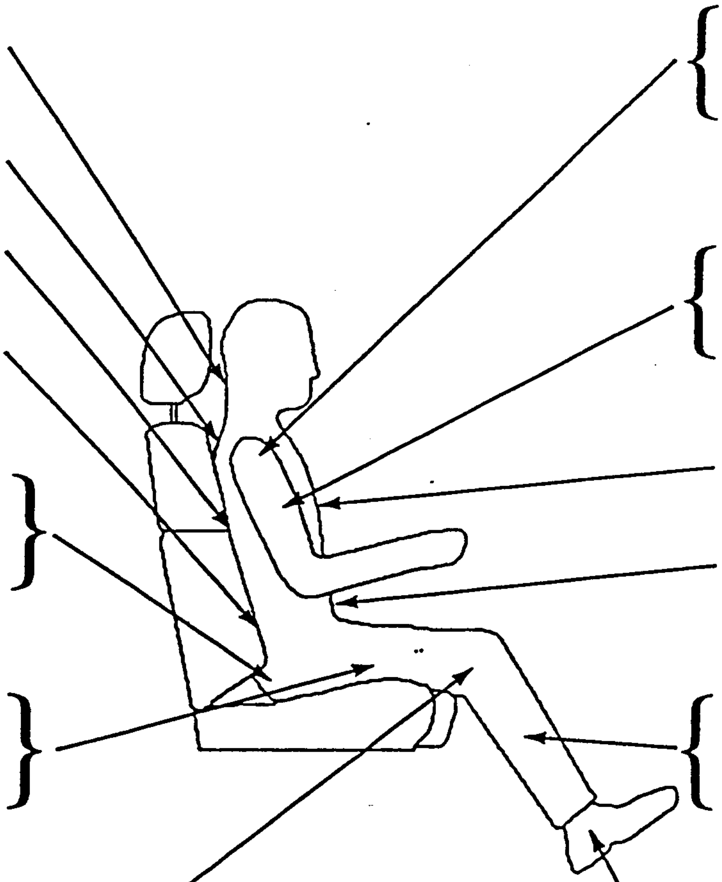
3
4

F. Comfort Evaluation 1

You have now been sitting in the rig for approximately 15 minutes. Could you now describe your feelings of comfort in each body area shown in the illustration below using the following scale.

1	Very comfortable
2	Moderately comfortable
3	Fairly comfortable
4	Neutral
5	Slightly uncomfortable
6	Moderately uncomfortable
7	Very uncomfortable

Please circle the appropriate number for each area.



Neck
1 2 3 4 5 6 7

Upper back
1 2 3 4 5 6 7

Middle back
1 2 3 4 5 6 7

Lower back
1 2 3 4 5 6 7

Left buttock
1 2 3 4 5 6 7

Right buttock
1 2 3 4 5 6 7

Left thigh
1 2 3 4 5 6 7

Right thigh
1 2 3 4 5 6 7

Left knee
1 2 3 4 5 6 7

Right knee
1 2 3 4 5 6 7

Left shoulder
1 2 3 4 5 6 7

Right shoulder
1 2 3 4 5 6 7

Left arm
1 2 3 4 5 6 7

Right arm
1 2 3 4 5 6 7

Chest
1 2 3 4 5 6 7

Stomach
1 2 3 4 5 6 7

Left calf
1 2 3 4 5 6 7

Right calf
1 2 3 4 5 6 7

Left foot & ankle
1 2 3 4 5 6 7

Right foot & ankle
1 2 3 4 5 6 7

Appendix 15

Anthropometric Data (Experiment 2)

Anthropometric Data (Experiment 2)

	Sample (n=14) Mean (SD) Range	Males (n=7) Mean (SD) Range (%)	Females (n=7) Mean (SD) Range (%)
Stature (mm)	1672 (115) 1475-1875	1755 (80) 1645-1875 (8-97)	1588 (78) 1475-1692 (2-91)
Weight (kg)	68 (14) 48-105	71 (8) 58-80 (8-68)	66 (19) 48-105 (2-99)
Sitting height (mm)	889 (55) 783-964	928 (32) 864-964 (10-93)	849 (44) 783-918 (3-97)
Buttock knee length (mm)	587 (42) 524-660	599 (37) 554-660 (9-98)	576 (47) 524-649 (6-99)
Knee height (mm)	511 (41) 444-601	534 (36) 493-601 (5-96)	488 (33) 444-551 (2-97)
Hip breadth (mm)	373 (43) 333-505	360 (16) 333-378 (17-73)	386 (22) 335-505 (18-99)
Upper limb length (mm)	732 (62) 637-870	771 (56) 710-870 (3-99)	693 (40) 637-745 (2-90)
Reciprocal Ponder Index	41.1 (2.3) 35-45	42.4 (1.6) 40-45	39.9 (2.2) 35-42

SD = Standard Deviation
% = Percentile value for British adults (Pheasant, 1990)

Appendix 16

Posture and Pressure Correlations (Experiment 2)

Correlation coefficients (Pearson's r) and their significance for posture and pressure variables with preferred and least preferred seats.

Pressure Variable	Correlation Coefficients (n=14)			
	Ankle Angle		Arm Flexion	
	Preferred Seat	Least Preferred Seat	Preferred Seat	Least Preferred Seat
Right Ischial Tuberosity (IT)				
IT Maximum	-.6900 **	-.4118	.1048	.0662
IT Mean	-.5327 *	-.4632 (a)	.6583 **	-.0146
IT Standard Deviation	-.5639 *	-.3228	-.1503	-.0696
IT Ratio Maximum	.5259 (a)	-.3537	-.1003	-.0632
IT Ratio Minimum	.4270	-.6389 *	.4322	.3446
IT Proportion	-.3983	-.5594 *	.4406	.1952
Right Thigh				
Thigh Maximum	.1556	.5725 *	-.2404	-.0844
Thigh Mean	.3914	.3900	-.0988	.0032
Thigh Standard Deviation	-.4516	.4651 (a)	.0069	-.0470
Thigh Ratio Maximum	.0527	-.2041	.0527	-.2041
Thigh Ratio Minimum	-.2845	.1991	-.2845	.1991
Thigh Proportion	.4756 (a)	.2518	-.2585	.3082
Low Back				
Back Maximum	-.3398	-.1202	-.0732	.4805 (a)
Back Mean	-.5242 (a)	-.1392	.2758	.1995
Back Standard Deviation	-.2861	-.0817	-.1282	.4530
Back Ratio Maximum	.2923	-.0945	.0738	-.2488
Back Ratio Minimum	-.0451	.2713	.1333	-.5107 (a)

	Elbow Angle		Neck Inclination	
	Preferred Seat	Least Preferred Seat	Preferred Seat	Least Preferred Seat
Right Ischial Tuberosity (IT)				
IT Maximum	.0383	.1777	-.5500 *	-.0560
IT Mean	.6146 *	.0453	-.5353 *	-.2858
IT Standard Deviation	-.2256	.0299	-.4990 (a)	.0381
IT Ratio Maximum	.3446	.1204	.3727	.2538
IT Ratio Minimum	.4146	-.3472	.2409	-.5083 (a)
IT Proportion	.3369	.0590	-.5877 *	-.3645
Right Thigh				
Thigh Maximum	.0588	.0248	.1290	.0616
Thigh Mean	.1304	.1301	.0972	-.1124
Thigh Standard Deviation	.1730	.1412	-.1862	.0864
Thigh Ratio Maximum	-.0089	-.1167	.0906	.0893
Thigh Ratio Minimum	.2496	.4268	-.4675 (a)	-.4343
Thigh Proportion	-.0370	.2368	-.0636	-.5392 *
Low Back				
Back Maximum	.1238	.3597	.0459	-.6429 *
Back Mean	.3400	.1344	-.4919 (a)	-.4967 (a)
Back Standard Deviation	.1363	.3075	.1338	-.5632 *
Back Ratio Maximum	-.1691	.0419	-.5073 (a)	.4238
Back Ratio Minimum	.0102	-.4586 (a)	-.1097	.7122 **

N.B. (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001.

Correlation coefficients (Pearson's r) and their significance for posture and pressure variables with preferred and least preferred seats (continued).

Pressure Variable	Correlation Coefficients (n=14)			
	Trunk-Thigh Angle		Knee Angle	
	Preferred Seat	Least Preferred Seat	Preferred Seat	Least Preferred Seat
Right Ischial Tuberosity (IT)				
IT Maximum	-.1609	.3274	-.5747 *	-.4054
IT Mean	.0518	.2052	-.3659	-.3158
IT Standard Deviation	-.2021	.1891	-.5565 *	-.4723 (a)
IT Ratio Maximum	.0527	-.2041	.3599	-.2142
IT Ratio Minimum	-.2845	.1991	.2764	-.4860
IT Proportion	.2291	-.1897	-.3931	-.7160 *
Right Thigh				
Thigh Maximum	.3970	.0626	.3192	.6283 *
Thigh Mean	.2955	.1449	.5215 (a)	.6323 *
Thigh Standard Deviation	.3296	.3775	-.1951	.3377
Thigh Ratio Maximum	.0527	-.2041	.3599	-.2142
Thigh Ratio Minimum	-.2845	.1991	.2764	-.4860
Thigh Proportion	.2291	-.1897	.4848 (a)	.3191
Low Back				
Back Maximum	.4722 (a)	-.2221	-.0562	-.2142
Back Mean	.2015	-.2004	-.3167	-.1792
Back Standard Deviation	.5927 *	-.2992	.0514	-.2590
Back Ratio Maximum	-.6467 *	.4695 (a)	-.0201	.3541
Back Ratio Minimum	-.1313	-.6467 *	-.2328	.2522

N.B. (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001.

Appendix 17

Posture and Pressure Correlations (Experiment 3)

Correlation coefficients (Pearson's r) and their significance for posture and pressure variables for limited and fully adjustable driving packages (males).

Pressure Variable	Correlation Coefficients (n=6)			
	Ankle Angle		Arm Flexion	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	.9634 **	.5037	.0211	-.1932
IT Mean	.9626 **	.1497	-.1814	-.8125 *
IT Standard Deviation	.9563 **	.6542	.0429	.0852
IT Ratio Maximum	-.9217 **	-.6139	-.1648	-.0710
IT Ratio Minimum	-.2834	.2214	-.6306	.1921
IT Proportion	.8833 *	.0932	.1594	-.0686
Right Thigh				
Thigh Maximum	.4945	.7805 (a)	-.1285	-.0672
Thigh Mean	-.4965	-.4472	-.5071	-.0062
Thigh Standard Deviation	.7436 (a)	.7495	-.0754	-.1289
Thigh Ratio Maximum	-.8364 *	.2972	.0012	-.0938
Thigh Ratio Minimum	-.7689 (a)	-.3100	-.6211	.0026
Thigh Proportion	-.1333	-.0493	.1166	.5894
Low Back				
Back Maximum	.1022	-.2018	.3667	.4677
Back Mean	.2491	-.0291	.1953	.4207
Back Standard Deviation	-.0781	-.5942	.3650	.3184
Back Ratio Maximum	.7276	.8280 *	-.4280	.1035
Back Ratio Minimum	.4470	.0061	-.2559	.0625

	Elbow Angle		Neck Inclination	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	-.1345	-.4147	-.7208	-.6144
IT Mean	-.2933	-.8813 *	-.6686	-.0492
IT Standard Deviation	-.1159	-.2384	-.7230	-.4922
IT Ratio Maximum	-.1799	.0495	.9622 **	.2302
IT Ratio Minimum	-.6520	-.2344	.5334	.2130
IT Proportion	.0499	.0251	-.9339 **	-.8147 *
Right Thigh				
Thigh Maximum	-.8964 *	-.4541	-.1928	-.0472
Thigh Mean	-.4487	.1236	.4501	.0925
Thigh Standard Deviation	-.7185	-.3546	-.7230	.3522
Thigh Ratio Maximum	.5936	-.1246	.5437	.1032
Thigh Ratio Minimum	-.0698	.2197	.7153	.7865 (a)
Thigh Proportion	.0554	.6974	-.2801	-.6750
Low Back				
Back Maximum	.5490	.7651 (a)	.0334	-.1583
Back Mean	.1242	.6699	.0878	-.0613
Back Standard Deviation	.7212	.7940 (a)	.0785	-.2479
Back Ratio Maximum	.0422	-.3667	-.4303	.0739
Back Ratio Minimum	-.7423 (a)	-.2568	-.1083	-.2109

N.B. (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001.

Correlation coefficients (Pearson's r) and their significance for posture and pressure variables for limited and fully adjustable driving packages (males continued).

Pressure Variable	Correlation Coefficients (n=6)			
	Trunk Thigh Angle		Knee Angle	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	-.0786	.4382	-.2565	.3042
IT Mean	-.2504	-.5545	-.5065	-.3083
IT Standard Deviation	-.0604	.5810	-.2270	.3114
IT Ratio Maximum	-.0931	-.6260	.1050	-.0286
IT Ratio Minimum	-.6157	-.3257	-.6874	.0389
IT Proportion	-.0637	.6139	-.3475	.4643
Right Thigh				
Thigh Maximum	-.8849 *	.3263	-.9057 *	-.0317
Thigh Mean	-.5654	-.2539	-.5581	.0708
Thigh Standard Deviation	-.6568	.1769	-.7723 (a)	-.4334
Thigh Ratio Maximum	.5635	-.5273	.7211	-.0284
Thigh Ratio Minimum	-.1120	-.4908	-.0302	-.5601
Thigh Proportion	-.2235	.9571 **	-.2954	.6858
Low Back				
Back Maximum	.7756	.6488	.6894	.2291
Back Mean	.3958	.6464	.2081	.0943
Back Standard Deviation	.8943 *	.4288	.8911 *	.2859
Back Ratio Maximum	.1367	.2238	-.2610	-.0888
Back Ratio Minimum	-.6902	-.2414	-.8921 *	.3206

N.B. (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001.

Correlation coefficients and their significance for posture and pressure variables for the limited and fully adjustable driving packages (females).

Pressure Variable	Correlation Coefficients (n=6)			
	Ankle Angle		Arm Flexion	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	.3358	-.0926	.3178	-.0757
IT Mean	.3891	-.3837	.0123	.6885
IT Standard Deviation	.0288	.1781	.6544	.8097 *
IT Ratio Maximum	.1449	-.6517	-.6877	-.6593
IT Ratio Minimum	-.6707	.2063	.2216	-.6606
IT Proportion	.3628	-.0149	.4503	.9789 ***
Right Thigh				
Thigh Maximum	-.0687	.6562	-.2886	-.0969
Thigh Mean	.1889	.5223	-.4168	-.5626
Thigh Standard Deviation	-.2637	-.2065	-.4346	.4278
Thigh Ratio Maximum	-.4323	.4147	.1773	-.4059
Thigh Ratio Minimum	.1260	-.0457	-.5242	.0132
Thigh Proportion	.1637	.7077	-.1217	.0282
Low Back				
Back Maximum	-.0371	.0701	-.4879	-.5656
Back Mean	-.2477	.6666	-.3256	-.5103
Back Standard Deviation	.0068	-.0487	-.6648	.5234
Back Ratio Maximum	-.0113	.4655	.4720	.0179
Back Ratio Minimum	-.1659	-.0739	-.2789	.4595

	Elbow Angle		Neck Inclination	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	.6467	.4893	-.2147	-.3861
IT Mean	.4544	.0494	1379	.0873
IT Standard Deviation	.6531	.5539	-.5920	-.6300
IT Ratio Maximum	-.2438	-.2099	.7598 (a)	.8832 *
IT Ratio Minimum	-.2862	.2053	-.0837	.5368
IT Proportion	.6536	.5546	-.3784	-.8126 *
Right Thigh				
Thigh Maximum	-.7196	.1926	.0217	-.0761
Thigh Mean	-.8437 *	.0528	.1900	.1671
Thigh Standard Deviation	-.4088	-.0523	.1658	-.1351
Thigh Ratio Maximum	-.0489	.1966	.1922	.0719
Thigh Ratio Minimum	-.1065	.2790	.7209	.0871
Thigh Proportion	-.7212	.4622	-.1995	-.4059
Low Back				
Back Maximum	.1905	-.2588	.2371	.5698
Back Mean	.1770	.0253	.1790	.2148
Back Standard Deviation	.1233	-.2150	.4269	.6169
Back Ratio Maximum	.6471	-.5414	-.3618	-.4281
Back Ratio Minimum	1.000	.6269	.3545	-.2551

N.B. (a)=$0.1>p>0.05$, * $p<0.05$, **$p<0.01$, ***$p<0.001$.

Correlation coefficients and their significance for posture and pressure variables for limited and fully adjustable driving packages (females continued).

Pressure Variable	Correlation Coefficients (n=6)			
	Trunk Thigh Angle		Knee Angle	
	Limited	Fully Adjustable	Limited	Fully Adjustable
Right Ischial Tuberosity (IT)				
IT Maximum	.0195	-.5248	-.4231	-.3802
IT Mean	.2502	-.2063	-.1519	-.0587
IT Standard Deviation	-.3910	-.5570	-.7416 (a)	-.4569
IT Ratio Maximum	.7288 (a)	.2686	.7566 (a)	.4022
IT Ratio Minimum	-.3028	-.0977	-.1604	.9092 **
IT Proportion	-.0572	-.7102	-.4954	-.7712 (a)
Right Thigh				
Thigh Maximum	-.1022	-.0315	.4409	.4983
Thigh Mean	.1223	-.1025	.6137	.8272 *
Thigh Standard Deviation	-.1483	.1516	.3577	-.4892
Thigh Ratio Maximum	-.0155	-.2831	-.2244	.6673
Thigh Ratio Minimum	.5240	-.4026	.3991	.3329
Thigh Proportion	-.1408	-.5269	.3715	.3815
Low Back				
Back Maximum	.2963	.3881	.4891	.6652
Back Mean	.3226	.1366	.4586	.8369 *
Back Standard Deviation	.3243	.3654	.5429	.6031
Back Ratio Maximum	.2884	.5025	-.1236	-.2860
Back Ratio Minimum	.5677	-.4811	.5352	-.3798

N.B. (a)=0.1>p>0.05, * p<0.05, **p<0.01, ***p<0.001.